Quality of drinking and recreational water in the Hunter New England region of New South Wales - Bridging the gap between research, practice and policy

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College of Science and Engineering

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Dedication

I dedicate this thesis to my beautiful wife Tariro with love, for encouraging me to pursue a Ph.D. research study. I thank her for the support in various ways. Special thanks to my three children Farirai, Grace, and Kuzivakwashe, for encouraging me to soldier on and forfeiting their much-valued time with me in order for me to succeed. I also dedicate this thesis to my late loving brother Thomas who taught me to always value education.

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Ethics Statement

The research work presented and reported in this thesis was conducted in accordance with the National Health and Medical Research Council (NHMRC) National Statement on Ethical Conduct in Human Research, 2007. The studies received human ethics research ethic approval from the following:

NSW Human Research Ethics Council Approval Numbers LNR/12/HNE/246; LNR/13/HNE/418 (Studies 1 & 3).

NSW Site-Specific Assessment Approval Number LNRSSA/12/HNE/247 (Study 1).

Hunter New England Health District Human Research Ethics Council (HNEHREC) Approval Numbers 12/08/15/5.02; 13/10/16/5.06 (Study 1 & 3).

Aboriginal Health and Medical Research Council of New South Wales Approval Number 984/13 (Study 3)

James Cook University Human Ethics Committee (HREC) Approval Numbers H5085; H5531 (Study 1 & 3).

Hunter New England Aboriginal Community Controlled Health Service express approval (Study 3).

Copyright Declaration

Signature

Date

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Acknowledgements

I would like to acknowledge the Traditional Owners and First Nations of Australia as the original custodians of this land, and pay my respects to the Elders past, present and future, for they hold the memories, the traditions, the culture and hopes of Aboriginal Australia. I would like to thank the Walhallow Local Aboriginal Land Council, Elders and the Walhallow Community for allowing me to carry out a study on consumer perceptions of drinking water in their community (Study 3). I heartily appreciate the leadership of Jason Allan, the Chief Executive Officer in this regard. I warmly appreciate and recognise Kylie Taylor, Natalie Allan and Ruth Williams for their guidance, contributions and support. Their enthusiasm profoundly motivated me to work with the Walhallow community.

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I would also like to recognise Associate Professor Michael Oelgemöller and Professor Jenni Judd, who volunteered to be my Principal and Secondary Advisors at James Cook University. By accepting to be my primary and secondary advisor respectively, A/Professor Oelgemöller and Professor Judd enabled James Cook University to consider my application positively. Their research process guidance and wise editorial advice throughout the study undoubtfully contributed to the success of this research.

I thank Dr. Paul Byleveld for agreeing to be my external advisor and for allowing me to use the NSW Health Drinking Water database as my primary data source (Study 1). Dr. Byleveld's insightful knowledge in water quality issues was instrumental in the success of the research study.

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I appreciate and acknowledge the contribution of NSW National Parks and Wildlife, and NSW State Parks for permitting the use their facilities to survey the provision and quality of drinking water in recreational parks (Study 2).

Statement of the Contribution of Others

Nature of Assistance	Contribution	Names, Titles, Affiliations
Intellectual assistance	Advisory Panel	A/Professor Michael Oelgemoeller was my principal advisor at James Cook University.
		Professor Jenni Judd was my secondary advisor at James Cook University.
		Doctor Paul Byleveld and was my external advisor from NSW Health.
		Associate Professor Peter Massey my external advisor from Hunter New England Local Health District.
	Copyediting, Formatting	Katharine J Fowler, in accordance with Parts D and E of the *Standards* of the Institute of Professional Editors (IPEd).
	Mentor	Professor David Durrheim, Director Health Protection, Population Health, Hunter New England Local Health District.
	Research assistance	Kylie Taylor, Natalie Allan and, Ruth Williams from Hunter New England Population Health assisted in community consultation; voice recorded interviews and water sampling in Study 3.
		Jason Allan, Chief Executive Officer for Walhallow Local Aboriginal, assisted in the community consultation process and ensuring cultural appropriateness in Study 3.
		The Legislation and Monitoring Team at Hunter New England Population Health contributed to the surveys in Studies 2, 3 and 4.
		Katrina Wall, NSW Health assisted in data collection in Study 1.
		Dirk Richards from NSW National Parks and Wildlife Service helped in water sampling at one of the recreational parks in Study 2.

	Statistical support	Michelle Butler and Julie Collins provided quantitative analytical support by helping me to plan and carry out the analyses. Professor Jenni Judd and Associate Professor Peter Massey assisted design and qualitative data analysis in Study 3. Sharon Hargreaves helped me by transcribing voice recorded interviews data in Study 3.
Financial support	Project costs	James Cook University, doctoral cohort program, provided funding for transport and accommodation during university residential block attendance throughout the study period. Support from GRS Cohort Programme (Travel and Accommodation) during residential block release. Stipend from Australian Postgraduate Award (APA) from the Australian Government. NSW Health and Hunter New England Population Health provided financial support for water testing in Studies 2, 3 & 4. A/Professor Michael Oelgemoeller provided financial support for data transcription in Study 3.
	Other funding	Hunter New England Population Health provided travel funding to enable me to undertake field work during working hours and present study findings at various conferences. NSW Health provided funding for water tests.
Use of infrastructure external to James Cook University	Office space, Transport, computer	Hunter New England Population Health provided me with office space, vehicle, equipment and supportive infrastructure for the duration of the study.

Chapters and Publications on Which this Thesis is Based and Contributions of Authors

Chapter #, Study #, Publication, and nature and extent of intellectual input from each author including the candidate

Chapter 1. ***Introduction:***

This chapter introduces and describes the objectives the thesis, and problem identification of the project, and lays out the structure of the thesis.

I was responsible for the concept, research theme and design of the thesis, and wrote the chapter. Jenni Judd provided editorial assistance.

Chapter 2. ***Literature review***

A literature review provides the theoretical basis for the research and helps to describe, evaluate and clarify the nature of the research project. This chapter reviews the literature in order to identify rural drinking water risks and to help to highlight the research gaps in drinking water management in rural New South Wales.

I designed and carried out the review. Paul Byleveld, Jenni Judd, David Durrheim and Michael Oelgemöller assisted in critically reviewing the chapter.

Manuscript 1:

Jaravani, F. **G**., Butler, M., Byleveld, P., Durrheim D. N., Massey, P. D., Collins, J., Judd, J. & Oelgemöller, M. (Under review). Drinking water quality in regional Hunter New England, New South Wales, Australia, 2001-2015. *Australasian Journal of Water Resources*, EATJ-D-18-00912.

Chapter 3. Study 1: Drinking water safety in rural Hunter New England, NSW, Australia 2001-2015

The main objective of NSW Health Drinking Water Monitoring Program is to continually improve drinking water quality in regional NSW. Assessing the routinely collected drinking water quality data would help to achieve this objective. This chapter describes how routinely collected drinking water quality data was used in a practitioner-led research effort to improve water quality management in Hunter New England region and state-wide.

> I designed and coordinated the investigation, data collection and analysis. I conceptually designed and wrote the manuscript.
>
> David Durrheim, Peter Massey provided high-level understanding of quantitative research methods, data collection and analysis and edited the manuscript.
>
> Katrina Wall helped with data collection.
>
> Michelle Butler and Julie Collins provided high-level understanding of statistical methods and assisted with editing the manuscript.

Chapter 4. Study 2: *Drinking water safety in recreational parks in northern New South Wales, Australia*

Private drinking water supplies contribute to the health of the citizens**.** Water supplies in recreational parks form part of the private water supplies in NSW. This chapter discusses how collecting data for a practitioner-led research project improved evidence translation to improve private drinking water quality.

> I was responsible for the concept, designed and coordinated the investigation, data collection and analysis. I designed and wrote the manuscript.
>
> David Durrheim, provided high-level research and analytical methods support and edited the manuscript.
>
> Michelle Butler provided high-level understanding of statistical methods and edited the manuscript.
>
> Paul Byleveld provided high level understanding of drinking water management systems, edited the manuscripts and coordinated the translation of the evidence state-wide.
>
> Jenni Judd, Peter Massey and Michael Oelgemöller provided critical review and editorial support of the manuscript.

Manuscript 2:

Jaravani, F. G., Durrheim, D., Byleveld, P., Oelgemoeller, M., & Judd, J. (2015). Drinking water safety in recreational parks in northern New South Wales, Australia. *Australasian Journal of Environmental Management*, 22(4), 432-445, doi: 10.1080/14486563.2014.984782.

Manuscript 3:

Jaravani, F. G., Byleveld, P., Durrheim, D., Judd, J., Oelgemöller, M., Butler, M., Massey, P. (In review). Improving drinking water safety in recreational parks through policy changes and regulatory support in the Hunter New England region, NSW, Australia. *Australasian Journal of Environmental Management*, TJEM-2017-0092.

Chapter 5. Study 3: *Closing the Gap: Understanding Aboriginal community beliefs, perceptions and attitudes towards drinking water supplies*

Working with Aboriginal communities in the Hunter New England region to improve health outcomes provides me with opportunities to share lessons learnt and promote the Australian Commonwealth *Closing the Gap* program. This chapter discusses how an environmental health practitioner-led research team, including community members, worked with an Aboriginal community to understand community concerns about the drinking water supply and how safe water can be promoted in the community.

I conceived and designed the concept. I was the Chief Investigator and coordinator for the project involved with community engagement, research ethics application, research questions development, data collection and analysis, report and manuscript writing, and reporting back to community and AH&MRC.

Kylie Taylor, Natalie Taylor provided community connection and cultural grounding, and guided participant recruitment, assisted in data collection and assisted in participant interviewing, reporting back to community and advocacy.

Jason Allan guided and organised community access, engagement and report back activities and connection to the Local Community Health Organisation for ethics application and approval processes.

Jenni Judd and Peter Massey provided academic and research level understanding of community participatory action research, development of mixed research methodology and supported the academic research process, data collection and analysis, report and manuscript design and editing and advocacy.

Michael Oelgemöller financed the professional transcription of the interview data and reviewed and editorial support of the manuscript.

David Durrheim provided critical review and editorial support of the manuscript.

Manuscript 4:

Jaravani, F. G., Massey, P. D., Judd, J., Allan, J., & Allan, N. (2016). Closing the Gap: the need to consider perceptions about drinking water in rural Aboriginal communities in NSW, Australia. *Public Health Research & Practice*, 26(2), e2621616

Manuscript 5

Jaravani, F. G., Massey, P. D., Judd, J., Taylor, K. A., Allan, J., Allan, N., Durrheim, D. N., & Oelgemoeller, M. (2017). Working with an Aboriginal Community to understand drinking water perceptions and acceptance in rural New South Wales. *The International Indigenous Policy Journal*, 8(3). doi: 10.18584/iipj.2017.8.3.4

Chapter 6. Study 4: *Water quality in recreational swimming sites in Hunter New England region, New South Wales, Australia*

Despite the safety of the drinking water provided in the communities, recreational water plays an important role in the enteric disease morbidity in rural areas of NSW. Moreover, drawing drinking water from sources used for recreational activities such as swimming adds to the drinking water treatment burden through water pollution. This chapter discusses the recreational water quality at popular swimming sites in the Hunter New England region. The objective was to prepare an argument for the closer management and monitoring of such recreational sites state-wide.

I coordinated the investigation, data collection and wrote the manuscript.

Philippe Porigneaux and Kelly Main were responsible for the concept, designed the project and edited the manuscript.

Michelle Butler provided high level understanding of statistical methods.

Paul Byleveld provided high level understanding of water management systems and water sample testing.

David Durrheim, Jenni Judd and Michael Oelgemöller edited the manuscript.

Manuscript 6:

Jaravani, F. G., Porigneaux, P., Main, K., Butler, M., Durrheim, D. N., Byleveld, P., Judd, J., & Oelgemoeller, M. (In review). Microbiological water quality at recreational swimming sites in regional Hunter New England, New South Wales, Australia. *Australasian Journal of Environmental Management*, TJEM-2018-0069.

Chapter 7. *Using practitioner-research to bridge policy, practice and research in drinking and recreational water management in rural Hunter New England region, New South Wales, Australia.*

This chapter discusses how practitioner-led research was successfully used in the four projects described above to bridge the gap between policy, research and practice in order to improve water quality in the region and statewide. The involvement of policy makers and academics improved the rigour of the process and promoted the translation of the research evidence into proposals for improvement of the water management system.

I wrote the manuscript.

Peter Massey provided input in design of the manuscript.

Paul Byleveld, Jenni Judd, David Durrheim, and Michael Oelgemöller, and Kelly Main provided critical review and editorial support for the manuscript.

Manuscript 7:

Jaravani F. G., Massey, P., Byleveld, P., Judd, J., Durrheim, D., Oelgemoeller, M. & Main, K. (In review). Using practitioner-research to bridge policy, practice and research in drinking and recreational water management in rural Hunter New England region, New South Wales, Australia. Environmental Perspectives EHP4863. (Submitted).

Chapter 8. *Conclusion, main findings, research impacts and recommendations for future research directions*

This chapter summarises the research findings and impacts and proposed further research work which is needed to continually improve public health using the promotion of routinely collected data and environmental health practitioner-led research.

I designed and wrote the chapter.

Peter Massey provided support editorial assistance on the design of the chapter.

Jenni Judd provided critical review and editorial assistance.

Statement of Authorship

I agree that the above statements about my respective contributions to authorship are true.

Author	Signature	Date
Fidelis Jaravani		
Michael Oelgemoeller		
Jenni Judd		
David Durrheim		
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Michelle Butler		
Kylie Taylor		
Jason Allan		
Natalie Allan		
Julie Collins		

Disclaimer

The views expressed in this thesis are those of the respective authors. The views conveyed do not necessarily represent the views of the affiliated organisations to which various article authors belong. Contributions by authors were made purely in an individual capacity and not as representatives of or on behalf of, their individual affiliated organisations unless specifically cited. The designations employed do not necessarily reflect the endorsement or expression of any opinion by named institutions unless expressly described. Their participation should not be taken as an endorsement by the affiliated organisations.

Some contributions may contain information obtained from deceased persons. The information could upset some readers, the authors wish no disrespect or distress to the respective famililies and the community.

Additional Courses Undertaken in Conjunction with the Thesis

Unit code	Unit
13-TM5524-TSV-LTD-SP1	Qualitative Research Methods for Tropical Health Practitioners
13-TM5516-TSV-BLO-SP5	Biostatistics for Public Health

Abstract

Introduction

Population health research may include primary data collection and analysis; analysis of existing data; and systematic reviews for problem definition, solution generation, and evaluation. The main objective of this thesis was to analyse routinely collected data and primary data to assess drinking and recreational water quality management in the Hunter New England region of New South Wales (NSW), Australia. This research was practitioner-led and designed to bridge the gap between research and policy in drinking water management in NSW. When used with a specific research goal, routinely collected data obtained for performance monitoring purposes is an important tool for improving the quality of water supplies. Such practitioner-led research may be directly translated into local practice to improve public health service delivery.

Continuous interactions between practitioner-researchers, academics, decision makers and other stakeholders throughout the research process provided impetus for evidence adoption through sustained evaluation of public health benefits. This thesis provides a firm foundation for the design of future environmental health interventions for the translation of research evidence to policy decision outcomes, leading to improved water quality and public health in rural areas.

Setting

In NSW, the *NSW Public Health Act 2010* (NSW Government, 2010) regulates water suppliers to provide safe water to consumers. NSW Health provides drinking water supply protocols that include monitoring, reporting, and public notifications. The NSW Health's Drinking Water Monitoring Program provides free water testing for suppliers throughout the state. Public water suppliers (utilities) are allocated barcoded-labels for the recommended number of samples for each water supply system each year. Compliance is measured by the adequacy of sampling, in which at least 98% should yield no *E. coli* detections. The Program centrally manages the internet-based NSW Drinking Water Database, which has recorded more than 20 000 sample results per year since 2001. Therefore, there is sufficient routinely collected data to assess drinking water quality in NSW.

Method

A Participatory Action Research (PAR) process was applied using a mixed methods framework. The practitioner researcher's research and collaborations with academics,

policy makers and stakeholders from the planning through to the implementation of projects ensured that expectations were clear. An *'adopt and intervene* as-we-go' philosophy was applied. The evidence was interrogated and areas of intervention were applied. Further projects were then designed to evaluate the identified areas of intervention.

Four approaches were taken to explore and bring about change in drinking water quality management through advocacy:

- Working with departmental staff to analyse routinely collected microbiological water quality data for reticulated water supplies to improve drinking water quality management within existing work budgets;
- Working with recreational parks authorities to collect and analyse data to assess and improve private drinking water management;
- Working with an Aboriginal community to assess reticulated drinking water supply quality and acceptance and promote consumption of safe drinking water; and
- Working with departmental staff to pilot *Enterococci* testing to assess recreational swimming water quality at popular swimming sites to design new policy to reduce public health risk.

Regular research briefs and reports to share findings, dissemination and advocacy through peer reviewed journal articles and presentations at professional conferences were used to share the research evidence to stakeholders, policy-makers and peer environmental health practitioners.

Results and outcomes

Public drinking water sampling adequacy significantly improved ($p = 0.002$) during the study period. Sampling adequacy was significantly lower in smaller populations ($p = 0.013$). *E. coli* detections significantly improved ($p < 0.0001$) but were significantly higher in smaller communities ($p < 0.001$). There was a strong inverse correlation between sampling compliance and *E. coli* detection ($p<0.001$; R^2 Linear = 0.72). NSW Health has assisted utilities to develop and implement Drinking Water Management Systems throughout the State.

All recreational parks developed and implemented drinking water quality assurance programs. All recreational parks that provided water but do not treat or regularly monitor the quality of the water supplies have installed appropriate warning signs by the NSW Private Water Supply Guidelines, to warn visitors. Private drinking water supplies have now been included in the *NSW Public Health Act*, and Private Drinking Water Supply Guidelines were amended to include the development and implementation of drinking water quality assurance plans.

Aesthetic factors such as water hardness, taste, colour, odours and societal values influence perceptions of risk and quality. Plans are underway to soften town water supply, as requested by the participating Aboriginal community, as this was a major barrier to consumption.

All swimming sites exceeded the threshold NHMRC *Enterococci* illness transmission recreational level of 40 CFU/100 ml. There is a need for risk-based water quality management at informal recreational swimming sites.

Conclusion

The research demonstrated that improving drinking water sampling frequency was associated with enhanced microbiological water safety. However, there is room for improvement in sampling adequacy and water quality (*E. coli* detections) in smaller communities. Further dialogue, research, and policy focus is needed that includes partnerships with discrete NSW Aboriginal communities, in order to develop a deeper understanding of their perceptions of drinking water and to encourage consumption of safe water.

This research promoted interaction between practitioners, managers and academics in environmental health program development to promote public health. The research clearly demonstrated how using routinely collected data coupled with primary data collection results in strong environmental health practitioner-led research with important policy outcomes. Future research should build on these key strengths, linking environmental health practitioners' fieldwork with productive collaborative networks between academics and policy makers, to promote the development of knowledge that provides evidence-based policy changes for public health benefit.

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Abbreviations, Acronyms and Synonyms

Abbreviation, Acronym or Synonym	**Name**
ABS	Australian Bureau of Statistics
ACWSP	Aboriginal Communities Water and Sewage Program
ADWG	*Australian Drinking Water Guidelines* 2011
AIDS	Acquired Immunodeficiency Syndrome
AIHW	Australian Institute of Health and Welfare
APA	Australian Postgraduate Award
ARC	Australian Research Council
ARIA	Accessibility/Remoteness Index of Australia
ASGC	Australian Standard Geographical Classification
AUD	Australian Dollar
$CaCO_3$	Calcium carbonate
$(Ca(HCO_3)_2$	Calcium hydrogen carbonate
CCP	Critical Control Point
CFU	Coliform forming Unit
CI	Confidence Interval
CIAP	NSW Clinical Information Access Portal
C.t	Contact times
CWP	Community Water Planner
DALYs	Disability Adjusted Life Years
DHSH	Department of Human Services and Health
DPI	Department of Primary Industries
DPIE	Department of Primary Industries and Energy
DWMS	Drinking Water Management System
E	East
EHS	Environment, Health & Safety
GRS	Graduate Research School
HACCP	Hazard Analysis Critical Control Point

HBTs	Health –based Targets
HIV	Human Immunodeficiency Virus
HNE	Hunter New England
HNEHREC	Hunter New England Human Research Ethics Committee
HNELHD	Hunter New England Local Health District
HNEPH	Hunter New England Public Health
HNEPHU	Hunter New England Public Health Unit
HREC	Human Research Ethics Committee
HRO	High-reliability Organisations
IFC	International Finance Corporation
ISO	International Standards Organisation
IWA	International Water Association
JCU	James Cook University
LNR	Low and Negligible Research
LNRSSA	Low and Negligible Research Site Specific Assessment
M	Metropolitan zone
MDGs	Millennium Development Goals
MORI	Market & Opinion Research International (UK)
MPN	Most Probable Number
NHMRC	National Health & Medical Research Council
NRMMC	National Resources Management Ministerial Council
NSW	New South Wales
NPWL	National Parks and Wildlife Service
NTU	Notional Turbidity Unit
ORs	Odds Ratios
PAF	Population attributable fractions
PAM	Primary Amoebic Meningoencephalitis
PAR	Participatory Action Research
PHU	Public Health Unit
ORs	Odds Ratios

PWSG	Private Water Supply Guidelines
QAPs	Quality assurance plans
R	Rural zone
Rem	Remote zone
RRMA	Rural, Remote and Metropolitan Areas
S	South
SDGs	Sustainable development Goals
SNAICC	Secretariat of National Aboriginal and Islander Child Care
SLA	Statistical Local Areas
SOP	Standard Operating Procedures
SWMS	Safe Work Methods Statement
TQM	Total Quality Management
UK	United Kingdom
UN	United Nations
UNICEF	United Nations Children's Fund
USA	The United States of America
UV	Ultra Violet
WHO	World Health Organization
WLALC	Walhallow Local Aboriginal Land Council
WQMS	Water Quality management System
WSPs	Water Safety Plans

Glossary

Term	Definition
Aboriginal	A person of Aboriginal or Torres Strait Islander descent who identifies as an Aboriginal or Torres Strait Islander and is accepted as such by the community in which he (she) lives.
Aesthetic water quality	A measure of a water quality characteristic that is associated with acceptability of water to the consumer; for example, appearance, taste and odour.
Close the Gap	An Australian Commonwealth strategy to improve Indigenous health to catch up with the rest of the citizenry.
Discrete Aboriginal community	Well established Aboriginal community living on a parcel of privately-owned Aboriginal land inhabited and managed by predominantly Aboriginal people.
EnteroTester Template V677	An easy-to-use Excel spreadsheet template designed for calculating 95th percentile statistics for *Enterococci* bacteria, standardised for comparison with the 95th percentiles used in the NHMRC *Guidelines*.
Hard water	A qualitative description that people use for the scaling actions of water containing Calcium salts.
Organoleptic	Ability to stimulate a sense organ, e.g. smell and taste.
Practitioner-led research	A form of research in which the practitioner leads a team of researchers, in collaboration with academic researchers, to examines aspects of their practice to improve the practice.
Private drinking water supply	A water supply which provides people with drinking water in from an independent water supply from rivers, creeks, bores, dams or water from rainwater tanks but does not include supplies provided by water utilities (i.e. town water) or individual household supplies.
Recreational park	An area of natural, semi-natural land or natural habitats intended for human enjoyment and recreation usually containing camping grounds, picnic areas, hiking, and other utilities used in recreational camping.
Reticulated water (Town water) system	A piped net-work of drinking water supplied to a town or community by a water authority for potable use.

Routinely collected data	Data collected as a service performance by-product and stored by practitioners during routine work.
Sampling adequacy	A ratio of the number of test samples collected to the number of samples expected per given period.
Sampling frequency	The number of samples collected per given period.
Warning signs	The signs that warn consumers of the safety conditions of a water supply designed to alert users and the general public about the hazards of inadequately treated not regularly tested, untreated or non-potable water.
Water disinfection	The process of removing, deactivating or killing of pathogenic microorganisms in a drinking water supply
Water hardness -	A quantitative measure of metal ions that are dissolved in the water usually measured as CaCO3.
Water supply system	The infrastructure for the collection, treatment, storage and distribution of drinking water through a system of pumps and pipes of water from source to consumers.
Water treatment	The process that uses chemicals and physical barriers, e. g. Filters, to reduce or eliminate particulates or protozoa that may cause waterborne disease, and to improve the aesthetic quality of the water to make it more acceptable for a specific end-use.
Water utility	An organisation, usually a local government that owns and operates large drinking water infrastructure (water supply systems) including bulk and retail water suppliers in Australia.

Preface: Background and Motivation

I believe that the triangulation of environmental health policy, practice, and research is imperative in promoting public health. The strengths in policy, practice, and research can be exploited to continuously generate and appraise evidence, gaps, and improvements in environmental health and public health at large.

I was born and bred in a Zimbabwean rural communal reserve, and raised drinking untreated water from shallow wells and water holes. I then studied Environmental Health and worked in metropolitan regions with modern water treatment facilities where the water quality is regularly monitored. I have always wondered how I, my tribe and many other Zimbabweans survived drinking and bathing in untreated, contaminated water. I vividly remember scooping Blue Green Algae from shallow wells and water holes before drinking or fetching water for domestic use. Visits to regional recreational parks, especially national parks without treated drinking water provisions, reminded me of my upbringing. My interests have developed in drinking water quality management in rural areas.

As a practicing Environmental Health Officer since 1987, I have continued to be interested in researching environmental issues that will enhance public health. Safe and adequate drinking water provision is part of public health service delivery which ensures the community's health. I have been working with drinking water utilities in the Hunter New England (HNE) region since 2006. Drinking water quality management is one of my core duties. Understanding the quality of drinking water in the area will assist me in finding ways to advocate for improved water quality resource prioritisation in rural areas of NSW.

My job has included working with Aboriginal communities. I am from an initially recessive ethnic tribe that has experienced considerable racism and prejudice. In 2008, the Council of Australian Governments endorsed a National Indigenous Reform Agreement to *Close the Gap* between Aboriginal and non-Aboriginal Australians regarding health, education, and socio-economic status. The objective of *Close the Gap Agreement* is to improve health indicators to close the life expectancy gap by 2031, and halve the gap in mortality rates for Aboriginal children under five by 2018. As part of *Closing the Gap* Hunter New England Local Health District (HNELHD) is obligated to deliver services in partnership with Aboriginal and Torres Strait Islander community organisations and encourage participation of Aboriginal communities in issues that affect their health. More recently I have been involved in the NSW Housing for Health and Aboriginal Communities Water and Sewerage Programs in the HNE region. My participation in these programs motivated me to learn more about

Aboriginal communities' drinking water supply perceptions and the contribution of drinking water quality to *Closing the Gap.*

Water quality assessment is necessary to continually evaluate and effectively manage water supplies. Contamination of water bodies which serve as drinking water sources is a common motivation for water quality studies and improvement programs. Research in rural water quality management will provide evidence-based arguments for improving water quality as required, and thus likely benefit public health in the countryside of NSW. This research will assist the NSW Ministry of Health in evidence-informed policy making and effective planning of drinking water safety management projects. This research project is therefore relevant to my field of work as an environmental health officer in HNELHD. The feasibility of this project was ensured by workplace management support through access to the NSW water quality database and established relationships with local water suppliers and environmental health practitioners.

My duties, which include guiding local government, assessing drinking and recreational water quality, investigating cases of contamination and the links between waterborne diseases and potable water supplies made this an ideal area of study. I firmly believe that a research degree will improve my professional practice by enhancing my knowledge in the areas of research methodologies, problem identification and solving, presentation to peer groups and publication of my findings for peer review.

Statement of Research Outcomes

The engagement of policymakers throughout the research project ensured that the outcomes were implemented not just in the Hunter New England Region but more broadly throughout NSW, in conjunction with other State drinking water management programs. The involvement of academic researchers and stakeholders ensured research rigour. Drinking water supply performance reviews, water treatment improvements, corrective maintenance actions and regulatory changes have been implemented in order to improve drinking water sampling adequacy and microbiological quality in regional New South Wales. The other policy and practice changes that occurred as a result of this body of research included:

- Risk-based drinking water quality management systems (water safety plans) incorporating critical control points for the water treatment (turbidity, residual chlorine); water distribution systems (reservoir integrity) and operational control points for raw water reservoirs, uptake systems, treatment optimisation are now mandatory in NSW since 2014;
- Customised electronic software for remote monitoring of critical control points (CCPs) exceedances and recording of operational data into the central water databases have been initiated to enhance transmission of field data in real time to understand and better manage the water supply systems the water supply systems;
- The use of routinely collected data as a research resource has galvanised NSW Health's recognition of the importance of supporting and funding regional utilities, especially those with limited engineering expertise and financial capacity to develop, implement and continually improve drinking water management systems by the *NSW Public Health Act 2010* (NSW Government, 2010) requirements. NSW Health has engaged specialist engineering contractors to assist small utilities to develop and implement drinking water management systems including targeted CCPs;
- The participation of the recreational parks authorities in the translation of this research evidence and other programs has enhanced closer cooperation and working relationships between NSW Health and local councils, government agencies and industry associations to promote awareness of the Drinking Water Quality Assurance program requirement for private water supplies and water carters state-wide. The *NSW Private Water Supply Guidelines* have been amended to include mandatory Drinking Water Quality Assurance programs. NSW Health has worked closely with local councils, government agencies and industry associations

to promote awareness of the quality assurance program requirement for private water supplies and water carters. NSW Health has published updated *NSW Private Water Supply Guidelines* and *NSW Guidelines for Water Carters*, water treatment fact sheets, and quality assurance program templates that can be easily adapted for different water supplies;

- Engagement and collaboration with Aboriginal communities improved trust and helped to build long term relationships. State-wide Aboriginal community water management plans have been integrated into Local Government Utility Drinking Water Management Systems, which are audited annually. Feasibility studies and consultations for water softening and improved palatability at the respective Aboriginal communities have been initiated; and
- Participation of the Aboriginal community has led to the boiling of rainwater before drinking to reduce potential disease outbreaks. The Local Aboriginal Land Council is considering scheduled rainwater tank cleaning. As it is not government policy to promote drinking rainwater when reticulated water is available, work is continuing to negotiate softening of water to make it more acceptable to the community.

This research presents important insights that water supply authorities need to consider when assessing health risks, choosing appropriate mitigation measures, and building business cases for water quality improvement programs in Aboriginal communities. Outcomes will be improved by involving communities in the process and by addressing community social concerns about town water supplies.

Chapter. 1 Introduction

> *"Ideally, drinking water should be clear, colourless, and well aerated, with no unpalatable taste or odour, and it should contain no suspended matter, harmful chemical substances, or pathogenic microorganisms…which, on the current state of knowledge, is safe to drink over a lifetime: that is, it constitutes no significant risk to health."* (NHMRC, 2011).

Access to sustainable safe drinking water is essential to public health and well-being. The supply of safe drinking water requires institutional political will, technological capacity, infrastructure, engagement, commitment, behaviour change, and recognition that drinking water is a human right (Schuster-Wallace, 2015).

Plate 1.1 : Drinking water should be clear, colourless, and well aerated: Reticulated water supply in the kitchen, Westdale, NSW 2013

The integrity of drinking water systems is of paramount importance. Occasionally, changes in source water conditions such as flooding, detection of *Escherichia coli* bacteria and blooms of cyanobacteria, coupled with operational problems, affect the integrity of the water. Monitoring drinking water quality is important to ensure effective control over the processes and activities that govern drinking water quality, that water quality is well managed and provides confidence to the water suppliers and the community that drinking water being provided is safe (NHMRC, 2011). Setting objective targets for water quality, documenting records, reviewing drinking water quality data and the corrective actions taken by utility staff whenever adverse changes in water quality occurred, is essential (Byleveld et al., 2016).

1.1 Thesis Background

Population health research is defined as the investigation and analysis of factors that influence the health status of communities, or population, and the testing and evaluation of policies and interventions to improve population health outcomes (Moore and Campbell, 2017). Population health research includes primary data collection and analysis, analysis of existing data, and systematic reviews for problem definition, solution generation, and evaluation. This thesis utilised both primary data collection and analysis of routinely collected data to assess drinking water quality management in the Hunter New England region of New South Wales, Australia.

In developed countries, small drinking water systems are widely described as posing quality management challenges due to their small consumer base, geographic remoteness, and financial capacity (McFarlane and Harris, 2018). In New South Wales (NSW) regional areas, local councils supply drinking water and monitor it according to the size of the population and the complexity of the supply system (Byleveld et al., 2008) as outlined in the *Australian Drinking Water Guidelines 2011*(ADWG) (NHMRC, 2011). Rural NSW drinking water supplies are highly susceptible to bacterial and chemical contamination problems. These include contamination by animal wastes and widespread use of pesticides and agricultural chemicals, and their significance to water quality cannot be over-emphasised (McKay and Moeller, 2001). Rural communities are more likely to experience outbreaks of waterborne diseases than their metropolitan counterparts because of limited financial capacity and the condition of ageing infrastructure (Kot et al., 2011). Adequate disinfection and proper maintenance and monitoring of the drinking water systems is vital to the protection of public health.

The perceived safety of drinking water in affluent communities means that there is little incentive for proactive cooperation beyond regulatory requirements (Jalba et al., 2010). There is growing international consensus that the most efficient way to achieving drinking water safety is through a commitment to a comprehensive approach to risk management (Byleveld et al., 2008; Hrudey et al., 2006; Rizak et al., 2006; Yasar et al., 2011). To facilitate this understanding, NSW Health developed the Drinking Water Monitoring Program (NSW Health, 2005), and devised a water quality database to monitor the safety of drinking water in the rural areas of NSW (NSW Health, 2017a).

Perceptions of drinking water quality play a significant role in determining effective engagement in preventing waterborne diseases. Inaccurate perceptions about potential public health threats have resulted in utilities not taking adequate risk management measures, resulting in detrimental public health impacts (Yasar et al., 2011). Public preferences for water supplies can lead to raw water sources being utilised more than treated water. Communities may face risks of waterborne diseases if these alternative sources are not adequately protected and monitored.

Researchers have studied the microbiology (Cretikos et al., 2010) and chemistry (Li et al., 2009) of NSW regional drinking water. However, there are no records of studies which have integrated drinking water quality with the social acceptability of the water for the New England region of NSW. Nor has any study of water source preference in discrete Aboriginal communities in the Hunter New England region been carried out.

There is a need for verifiable water quality data analysis to help regional/rural water utilities provide safe water to consumers. Such data analysis would provide useful information about current conditions and the likely public health burden related to the water supply. The analysis would also reveal the extent of major water quality problems and inform future investment priorities (Rizak et al., 2006).

The objective of this study is to assess drinking water monitoring compliance in the Hunter New England (HNE) region of New South Wales relating to water sampling adequacy and *E. coli* detections. This chapter will introduce the background to the research study, its aims and objectives and an overview of the study.

1.2 Study Area

This research was conducted in the rural areas of the Hunter New England Local Health District of New South Wales, Australia. The Hunter region of New England is situated approximately between 29^{O}-33^{O}S and 149^{O}-153^{O}E (Figure 1.1).

Hunter New England Health was created on 1 January 2005, following the merger between Hunter, New England, and the Lower Mid-North Coast local government areas of Gloucester, Greater Taree, and Great Lakes. It stretches from the Queensland border in the north to Lake Macquarie in the south. Hunter New England covers an area of approximately 128,469.6sq km and has a population of about 911,295 people, 42,047 (4.6%) being Aboriginal Peoples (ABS, 2017). Rural HNE has a population of about 404,240 people including 26,074 (6.5%) Aboriginal Peoples (Table 1.1) (ABS, 2017). More than 60% of HNE Aboriginal people reside in the rural areas of the district.

Figure 1.1 Map of Hunter New England (study area) (Hunter New England Area Health Service, 2008)

Table 1.1 Population by drinking water utility, regional Hunter New England, 2015 (ABS, 2017)

Utility	Male	Female	Total Population	Housing units	Population served with town water	Aboriginal population	Aboriginal population %
Armidale	12073	13245	25318	9132	24100	1595	6.3
Glen Innes	4459	4540	8999	3629	6650	504	5.6
Gunnedah	6406	6399	12805	4753	10329	1447	11.3
Guyra	2285	2266	4551	1684	932	455	10
Gwydir	2604	2464	5068	2074	2860	193	3.8
Inverell	8295	8641	16936	6295	12480	1102	6.5
Liverpool	3915	3844	7759	3049	5503	846	10.9
Midcoast Water	79664	81758	161422	61534	62428	6941	4.3
Moree	7196	6857	14053	5217	12071	2923	20.8
Muswellbrook	9068	8141	17209	5997	13264	929	5.4
Narrabri	7038	6761	13799	5124	10411	1476	10.7
Sealrocks	N/A	N/A	131	107	200	N/A	N/A
Singleton	12630	11441	24071	8163	20127	891	3.7
Tamworth	30304	30817	61121	22010	53015	5134	8.4
Tenterfield	3472	3514	6986	2866	3550	468	6.7
Upper Hunter	7400	7137	14537	5514	7470	567	3.9
Uralla	3210	3201	6411	2276	2900	378	5.9
Walcha	1546	1518	3064	1265	1760	224	7.3
Total	201565	202544	404240	150689	250050	26074	6.5

The region is one of the richest agricultural production areas in the state. Sheep and cattle grazing, poultry production, irrigated cotton and cereal crops are the main contributors. Hunter New England is also rich in a variety of other resources such as coal and coal seam gas (Department of Planning and Infrastructure, 2012). The main river systems of the region include the Namoi, Gwydir, Macintyre, Hunter, and Manning Rivers. The region also contains the upper reaches of the Clarence and Macleay rivers.

1.3 Exclusions

The metropolitan city of Newcastle and the adjoining Lake Macquarie, Maitland, Cessnock and Dungog Local Government areas were excluded from this study because they are served by Hunter Water Corporation, under a particular Act of Parliament governing its performance. The towns of Boomi, Garah, Gurly and Weemelah were excluded because they are supplied with declared non-potable water supplies and are on permanent boil-water advisories. These non-potable supplies belong to the same drinking water utility. They are included in the database and samples were routinely taken and tested to warn the public of the risk involved on a monthly basis from 2002 to 2014.

1.4 Demography of Hunter New England

There are three major classifications of rurality or remoteness in Australia:

- Rural, Remote and Metropolitan Areas (RRMA);
- Accessibility/Remoteness Index of Australia (ARIA); and
- Australian Standard Geographical Classification (ASGC) (DPIE & DHSH, 1994).

RRMA is based on distance to service centres (towns) and a measure of distance from other people (population). ARIA and ASGC are mainly based on distance from service centres (accessibility). NSW drinking water services are dependent on the population served. This project chose the RRMA classification as the most relevant definition of rurality. The RRMA classified Australia into seven categories - 2 metropolitan, 3 rural and 2 remote - based on Statistical Local Areas (SLA) (Table 1.2). Each SLA is categorized by population numbers and an index of remoteness using distance factors and population density (AIHW, 2004).

Table 1.2 Structure of the Rural, Remote and Metropolitan Areas (RRMA) classification (DPIE & DHSH, 1994).

Zone		Category
Metropolitan zone	M1	Capital cities
	M2	Other metropolitan centres (urban centre population 100,000 or larger)
Rural zone	R1	Large rural centres (urban centre population 25,000-99,999)
	R2	Small rural centres (urban centre population 10,000-24,999)
	R3	Other rural areas (urban centre population < 10,000)
Remote zone	Rem1	Remote centres (urban centre population > 4,999)
	Rem2	Other remote areas (urban centre population < 5,000)

In the Hunter New England (HNE) region there is one Metropolitan area, two R1 centres, five R2 centres and 59 R3 centres served with potable drinking water supplies (Fig 1.2). The R3 centres can be further divided into three Rem 1 and 56 Rem 2 centres. However, in this study, the term rural is used to denote both rural and remote zones (AIHW, 2004). There are 18 public drinking water suppliers and 66 potable water supply systems registered in rural Hunter New England. In addition, there are small private suppliers serving national parks, roadhouses, rest areas, and campgrounds. These may qualify as remote centres. Data on the registered supply systems is available on the secured log-in NSW Drinking Water Database (NSW Health, 2017a).

Figure 1.2 Map indicating rural, remote and metropolitan areas served with potable drinking water supplies, regional Hunter New England, NSW, 2016

1.5 Statement of the Problem

The United Nations (UN) General Assembly declared the period from 2005 to 2015 as the International Decade for Action, "*Water for Life*" (WHO, 2011a). The quality of drinking water is a fundamental environmental determinant of public health (WHO, 2011a). Drinking water quality interventions, coupled with improved sanitation and hygiene can reduce waterborne diarrhoea in a population (deWilde et al., 2008). 842 000 people (361 000 children under five years old) are estimated to die each year from diarrhoea due to unsafe drinking-water, sanitation, and hand hygiene. Contaminated water alone causes 502 000 deaths globally every year (WHO, 2018a). A basic facility like public drinking water is critical in the appraisal of public health risks.

Drinking water quality management is the foundation for the primary prevention and control of waterborne enteric diseases (WHO, 2011b).

Water is needed for drinking, cooking and food preparation, bathing, cleaning, personal hygiene, and recreation. Water should be free from pathogenic microorganisms and toxic chemicals and aesthetically attractive, with no odour, colour or taste, and be acceptable to consumers (NHMRC, 2011) to fulfil these functions (Fig. 1.3).

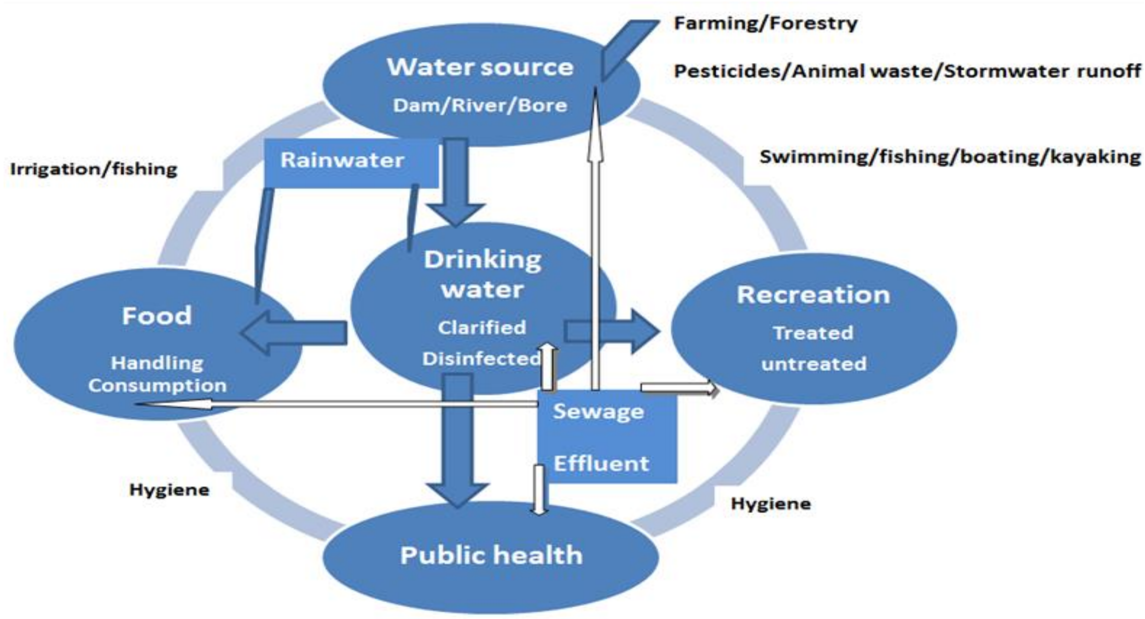


Figure 1.3 Relationship between drinking water and public health in regional Hunter New England.

In the rural areas of HNE, some drinking water sources are also used for recreational purposes. Dams and rivers may be used for both drinking water and recreation. Groundwater may be used for drinking water and filling swimming pools.

1.5.1 Policy, guidelines, and regulation

The Australian Research Council (ARC) considers water as a critical resource. Provision of safe and adequate water supplies is a key Australian government initiative. The ARC's *National Research Priorities and their Associated Priority Goals* recognised water as its priority goal number one for *"an environmentally sustainable Australia"*. Safe drinking water is one of the national research priority goals for *"promoting and maintaining good health*" research priorities (ARC, http://www.arc.gov.au/pdf/nrps_and_goals.pdf). "*Preventive healthcare*" and "*strengthening Australia's social and economic fabric"* are the two most relevant priority goals. These two goals encompass medical research, health, humanities, and social science, to produce outcomes that contribute directly and indirectly to improved health for Australians through evidence-based primary prevention strategies (NHMRC, 2011).

In New South Wales, Australia, water utilities operate under guidance from NSW Health and NSW Department of Industry Water to ensure the supply and safety of drinking water at all times. *The Public Health Act 2010* (NSW Government, 2010) and *Public Health Regulations 2012* (NSW Government, 2012) have made drinking water management plans a legal requirement from 2014. The *Act and Regulation* are supported by the *Australian Drinking Water Guidelines 2011* (ADWG). ADWG were legally adopted by NSW Health to support the *Public Health Act 2010* and guide water utilities. The ADWG provide detailed advice and requirements for all drinking water supplies in Australia. Drinking water utilities have a responsibility to ensure that the water is safe, and if it is not safe, then the consumers are warned (NSW Health, 2014). NSW Health has been working to support the development and implementation of management systems by water utilities to ensure safer water supplies. The impact of the support is not yet known. NSW adapted the Hazard Analysis and Critical Control Points (HACCP) principle to help develop the management systems (Byleveld et al., 2008). This approach is commonly used across Australia and around the world, and is considered industry best practice.

Drinking water monitoring by Australian rural water utilities is a necessary part of water quality management. Experience with waterborne disease threats and outbreaks has shown that compliance monitoring to numerical limits does not guarantee the safety and quality of drinking water supplies (Rizak and Hrudey, 2007). Microbiological sampling adequacy remains weak in many areas of regional NSW (Cretikos et al., 2010). During 2001-2007 almost 40% of drinking water systems had rates of microbiological non-compliance greater than the ADWG standards (Cretikos et al., 2010). One-quarter of regional drinking water systems had rates of *E. coli* detection more than twice the ADWG value. Further, nine (8%) drinking water systems in NSW did not supply disinfected water at the time of the review in 2007 (Cretikos et al., 2010). This research tries to find out if there has been some improvement.

1.5.2 Drinking water in discrete Aboriginal communities

NSW Health has included the discrete Aboriginal communities in the Drinking Water Monitoring Program (NSW Health, 2005). The development of drinking water management plans plays a fundamental role in providing safe drinking water to Aboriginal communities in rural NSW (Byleveld et al., 2016). Risk-based water management plans have been implemented in Aboriginal communities in Australia. However, this approach may not ultimately address the waterborne disease burden risk in rural areas. Drinking water in rural areas is not only about water quality, quantity, affordability, and accessibility, but consumers' socio-cultural beliefs, practices, behaviours, and perceptions (Sobey, 2006).

There is need to look beyond compliance requirements to ensure that consumers are satisfied that the supplies are safe and meet customary values.

Human psychology and human nature must be considered in the assessment of the potential public health risks posed by drinking water quality (Davison et al., 2010). The link between drinking water quality and customary values is important for Aboriginal communities, whose perceptions of drinking water extend beyond quality (Barber & Jackson, 2011a; Barber and Jackson, 2011b; Moggridge, 2010). Satisfaction of traditional values is paramount. Such values, if not known or understood by the water utilities, compromise safe water provision as the water may not be utilised for the intended purpose, and unsafe water sources used instead. Collaboration between health authorities, the water sector, and consumers is required to satisfy both communities' health and cultural water perceptions (Bridge et al., 2010).

The water suppliers regularly monitor and report on drinking water quality in Aboriginal communities in terms of microbiology, chemistry, pesticides, disinfection by-products, and radiological nuclides. However, despite the investment, no study has been carried out to discover how the communities perceive the reticulated public water supplies in the HNE region. Research, with community participation, exploring community perceptions of drinking water is therefore necessary.

1.5.3 Private drinking water supplies

A private water supplier is any person who supplies drinking water in the course of a commercial undertaking (other than that of supplying bottled or packaged drinking water) or any person who receives water from a public supplier and who supplies drinking water from a water carting vehicle in the course of a commercial undertaking (water carter) (*NSW Public Health Act 2010*) (NSW Government, 2010). This definition excludes water supply by private households for their own consumption.

Some of the greatest public health risks are those served by transient non-community water systems in national parks, rest areas and campgrounds (Sobey, 2006). These water supplies are usually small and may be poorly designed, maintained, and managed. The quality of such water supplies is generally unknown. The water is commonly rudimentarily treated or not treated at all. The *NSW Private Water Supply Guidelines* 2014 assists private operators in complying with the requirements of the ADWG (NSW Health, 2014). These water supplies are the most vulnerable to contamination and potentially pose health risks to consumers. The potential for the transmission of waterborne disease is highly probable as the source may be of poor quality (Sobey, 2006). Consistent oversight to ensure that regulatory standards are the same as those of public water supplies is generally lacking. No study has been carried out to assess the general quality of private water supplies in the HNE region and how private water suppliers comply with the requirements of the NSW *Private Water Supply Guidelines* and the ADWG. There is a need to research and set new and better priorities for drinking water in these facilities.

1.5.4 Recreational swimming water quality

Swimming sites have been implicated in waterborne disease outbreaks in Australia (Hall et al., 2006a). Similar outbreaks have been reported elsewhere (Craun and Wade, 2008; Hellard et al., 2000). Between 2001 and 2007 OzFoodNet Australia recorded 54 gastroenteritis outbreaks attributed to waterborne infections; 78% (42/54) of these were attributed to recreational water (Dale et al., 2010).

The Australian *Guidelines for Managing Risks in Recreational Water* 2008 guide harmonised management of the coastal, estuarine and recreational water through assessment and management of local factors that may lead to hazards (NHMRC, 2008). These guidelines are promoted for public recreational, health and well-being purposes. However, in NSW, designation of swimming sites and management of faecal contamination in inland waters is uncommon and data is scarce, although inland freshwater resources have high recreational values. Research to assist decision making in this regard is therefore necessary, since the same water is often used as a drinking water source.

1.6 Outline of the Thesis

Ensuring safe drinking water is a key activity for NSW: Population Health Priority 4 for 2012–2017: Build and maintain healthy environments (Population and Public Health Division, 2012a). Drinking water research fulfils one of the priorities and enablers, that is, to "Increase the use of research evidence in NSW Health population health policies and practice" (Population and Public Health Division, 2012a pp 5-6). The goal of this research study is to minimise waterborne diseases in rural areas of Hunter New England (HNE). This goal will be achieved through understanding the current public health risks posed by drinking and recreational water in rural areas of HNE and using the research to inform public health policy and decision making for rural areas of NSW. The project aims to close four identified knowledge gaps:

1. The public health risk associations of reticulated drinking water supply previously demonstrated in NSW have not been described in rural HNE.

2. The quality of drinking water supplies in some NSW National Parks is not monitored, and the associated risks are unknown.
3. Aboriginal people's perceptions and acceptance of the reticulated water supplies in NSW are not understood by the drinking water authorities.
4. Informal swimming sites in NSW are unregulated, and the quality of the bathing water is not known.

1.6.1 Aim and objectives

As an Environmental Health Officer, my duties include working with local governments to assess drinking and recreational water quality; investigating cases of water contamination; and exploring the links between waterborne diseases and potable water supplies. I strongly believe that this research, which involves environmental health practitioners, policymakers and academics, will enhance environmental health practice by narrowing the gap between practice, research and policy. The research will not only boost my personal knowledge in research methodologies, problem identification and solutions, but will give me practice in presenting to peer groups and writing publications of findings for peer review. The research will also contribute to evidence-based practice and policy development.

1.6.1.1 Aim

The research aim is to contribute to evidence-based policy decisions to improve drinking water quality in regional areas of NSW. Using participatory action research, the study aims to utilise practitioner experience to encourage the application of research outcomes by policy decision-makers and practitioners. This collaboration between experienced researchers, policymakers, and drinking water consumers will assess drinking water quality and user satisfaction. The goal is to maximize translation of the research evidence into outcomes to improve water quality in the region.

1.6.1.2 Objectives

The objective of this study is to use practitioner-led research to improve drinking water quality management to enhance evidence-informed policy on drinking water quality in rural areas of Hunter New England region. The overarching objective the study is to produce verifiable evidence that can be used to guide drinking water policy in rural areas at the local, state and national level to enhance public health. To achieve this objective, the research study will:

- Work with environmental health practitioners, policymakers, academics and relevant stakeholders to assess how water utilities in the rural areas of Hunter New England have performed against the *Australian Drinking Water Guidelines* since 2001;
- Present an overview of public health risks posed by drinking water quality in the rural areas of Hunter New England as a basis for evidence-informed policy decisions on drinking water risk management;
- Work with environmental health practitioners, policymakers, academics and relevant stakeholders to promote meaningful and objective stakeholder interactions and illustrate how collaborative relationships could be integrated with risk management for the benefit of environmental health practice and research;
- Work with relevant recreational parks authorities to assess how national parks drinking water supplies in the Hunter New England region are conforming to the *NSW Private Water Supply Guidelines*;
- Seek a shared understanding with a selected rural Aboriginal community about the quality of the drinking water supplies, advantages of consuming water of assured quality, and to explore community concerns about reticulated water supplies;
- Document the public health risks posed by recreational water quality in the rural areas of Hunter New England as a basis for informed decisions on risk management; and
- Present and discuss gathered evidence with peer practitioners, policymakers and stakeholders to facilitate and enhance the practical translation of the research evidence into the implementation of recommendations.

1.6.2 Goal

To narrow the gap between environmental health practice, research and policy to enhance drinking water quality management in rural NSW, Australia.

1.6.3 Guiding research questions

1. What was the level of compliance with the *Australian Drinking Water Guidelines* microbiological standards of drinking water supplies to minimise public health risk in rural Hunter New England for the past 15 years (2001 to 2015)?
    - Are the associations previously demonstrated in NSW replicable at the Hunter New England level and consistent over time?

- Has the change in regulatory requirements from 2012 been associated with improvements in compliance with the *Australian Drinking Water Guidelines*?

2. What is the level of conformity of private water supplies in recreational parks with the NSW Private *Drinking Water Supply Guidelines*?
    - Is there a microbiological risk in these private water supplies?
    - How does the provision of an interventional field survey, and public health guidance result in risk management improvements?

3. What are the main factors that influence an Aboriginal community's perceptions of the reticulated drinking water supplies in a rural area of Hunter New England?
    - Do Aboriginal communities in rural areas of HNE trust the reticulated drinking water supplies in their communities?
    - What are the beliefs underpinning trust or distrust?

4. Is the quality of recreational water in informal swimming sites in rural Hunter New England safe?
    - How do the swimming sites' neighbourhood affect the water quality?
    - What is the level of recreational water contamination in relation to indicator bacteria?

5. Is the level of conformity of private water supplies in recreational parks with the *NSW Private Drinking Water Supply Guidelines*?
    - Is there a microbiological risk in these private water supplies?
    - How does the provision of an interventional field survey, and public health guidance result in risk management improvements?

6. What are the main factors that influence an Aboriginal community's perceptions of the reticulated drinking water supplies in a rural area of Hunter New England?
    - Do Aboriginal communities in rural areas of HNE trust the reticulated drinking water supplies in their communities?
    - What are the beliefs underpinning trust or distrust?

7. Is the quality of recreational water in informal swimming sites in rural Hunter New England safe?
    - How do the swimming sites' neighbourhood affect the water quality?
    - What is the level of recreational water contamination in relation to indicator bacteria?

1.7 What is the Significance of the Research?

The significance of this body of research will be to narrow the gap between environmental health practitioners as researchers, policymakers, academics and the community in their ability to synthesize research outputs and apply existing knowledge (routinely collected data) to improve drinking water quality. Researchers should be able to adapt existing knowledge to local conditions by utilising the knowledge of local stakeholders, local policymakers, water supply practitioners, and the respective communities. The successful assessment of, and response to, environmental threats to health depend on effective collaborations between policymakers, public health practitioners and researchers across government agencies, industry and academia. This collaboration ensures that real and potential threats are accurately assessed and controlled (McAnulty, 2016).

The assumption that interventions are not the responsibility of only the researchers, as they seek to influence others for action instead of taking action themselves is challenged when community members are placed as equal partners in the research process. Therefore, the responsibility for action is seen as a joint responsibility of the two – researchers and research-partners (Khan et al., 2013). Understanding this paradigm helps researchers to effectively translate research into practice because it helps participants to understand the strategies required to develop and effect change (Wheelahan, 2001).

1.8 Thesis Layout

This research study combines practice-based research and participatory action research based on the practitioner/researcher's day to day practice to coordinate drinking water quality management actions from water suppliers, consumers, and policymakers. I used multiple methodologies within a participatory action research process, including quantitative and qualitative approaches, to use information, policy changes, and behavioural changes from the participants in four distinct studies:

- Drinking Water monitoring and compliance;
- Recreational parks water safety;
- Drinking water preferences and acceptance in an Aboriginal community; and
- Recreational swimming water safety to achieve the aims and objectives of the research (Figure 1.4).

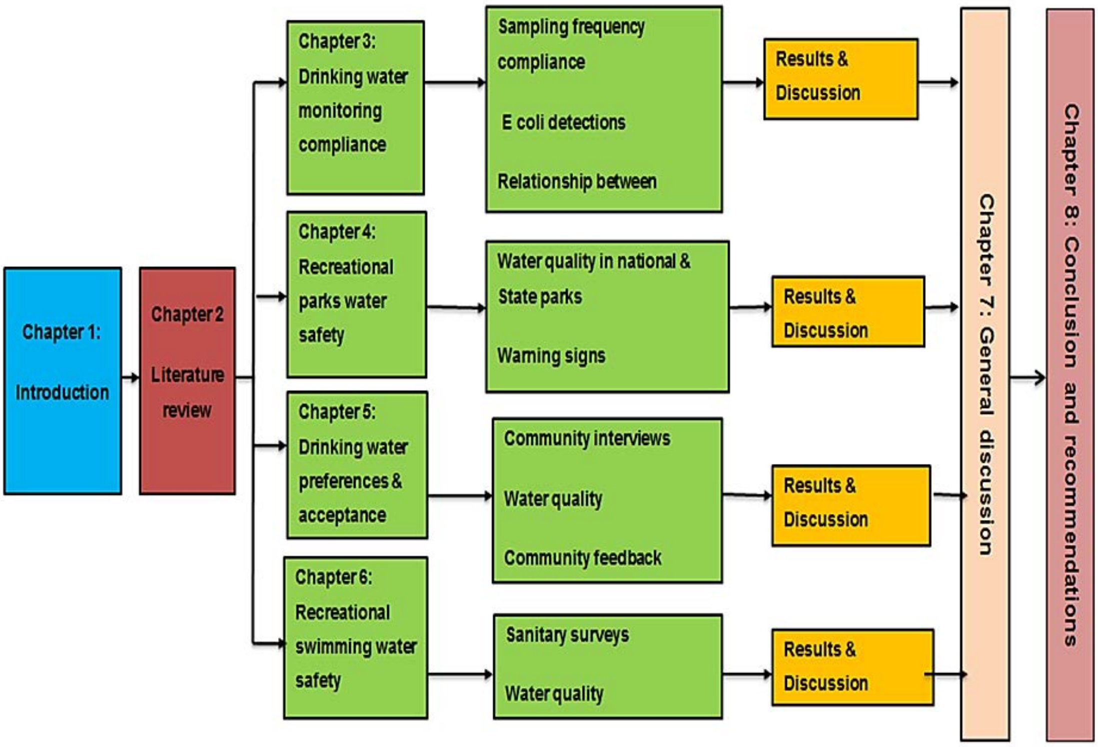


Figure 1.4 Structure of the thesis

Chapter 1: This chapter introduces the research project and highlights the background and purpose of the study. The introduction also establishes the objectives and research questions of the research project. A summary of the methodology is outlined. The detailed methodology will be included within each of the four studies.

Chapter 2 outlines a narrative literature review for the whole project highlighting drinking water gastrointestinal outbreaks resulting from poor drinking water management that have occurred throughout the world. The literature review is used to develop the research rationale. Policymakers, including the local public health directorate and NSW Health water quality management team, edited the literature review to justify the need for research and solicit support and participation of the policymakers.

Chapter 3 presents the first study, which comprehensively analyses existing routinely collected rural water quality data to assess the potential public health risks in rural areas of HNE drinking water supplies against the baseline requirements of the NSW Drinking Water Monitoring Program (NSW Health, 2005). This chapter assesses the impact of incremental public health measures taken to improve compliance, including water sampling adequacy and *E. coli* detections and to inform additional measures that may be required.

Chapter 4 presents the second study, which deals with the safety of drinking water in the recreational parks of the Hunter New England region. Recreational parks' drinking water quality management was assessed against compliance with the *NSW Private Water Supply Guidelines.*

Chapter 5 presents a case study of Aboriginal consumer perceptions and attitudes about drinking water supplies in an Aboriginal community. Participatory action research was undertaken with volunteer members of the community, with the aim to assist the community to make self-informed decisions on choosing appropriate and safe drinking water sources and to determine how to address and improve their water quality

Chapter 6 presents the fourth study, which analyses how the microbiological safety of the recreational waters can contribute to public health risk. The fourth study quantitatively looked at the quality of selected popular informal swimming sites in the region.

Chapter 7 presents a summary of the research findings and outlines how a practitioner-led research project can be utilised to bridge the gap between research and policy decision-making. The chapter also summarises the impacts of the research project and lessons learnt.

Chapter 8 discusses the conclusions and recommendations for future research. The chapter also discusses the future direction of drinking water quality management beyond the minimum regulatory requirements, and how to communicate the research findings to the relevant stakeholders.

The thesis will include a list of appendices and data tables from the data capture.

1.9 Conclusion

Drinking water is a critical resource and human right. The ADWG have recently been revised to enhance the risk-benefit approach to drinking water safety by integrating the source-to-consumer principle. The *NSW Public Health Act, 2010* and Public Health Regulations 2012 (NSW Government, 2012) make the establishment of drinking water management plans compulsory from January 2014. This study will assist policy makers in establishing whether there have been incremental benefits from the continued revision of guidelines and legislation. Public health risk analysis will assist with advocacy for improved resource allocation and prioritisation against other pressing needs in rural NSW.

The quality of drinking water in most NSW National Parks is unknown. The research will expose the public health risks posed by poor quality water supplies in parks and the need for water quality monitoring.

Aboriginal communities' perceptions of drinking water are likely to go beyond water quality. Inequalities in water supplies were identified in the NSW Aboriginal Communities Water & Sewerage Program respectively. Understanding the factors that influence Indigenous People's perceptions and cultural values of drinking water may encourage communities to consume water of assured quality.

There is no legislation that controls water quality in informal recreational swimming sites in NSW. To my knowledge, no study has been carried out to assess the quality of water in such environs in rural HNE, yet swimming sites are popular recreational destinations in rural NSW. The research will document the public health risks posed by informal swimming sites and enhance the regulation of such popular facilities in order to promote public health.

Chapter. 2 Literature Review

2.1 Introduction

Provision of adequate and safe drinking water is requisite to achieve the Millennium Development Goals (MDGs) (Bain et al., 2014). In 2004, the Bonn Charter, in support of the World Health Organization' s (WHO) Guidelines for Drinking-Water Quality concluded that "*Access to good, safe drinking water should be the right of every human"* (IWA, 2004). WHO Resolution 64/24 of May 2011, in support of the Millennium Development Goals, calls on Member States to ensure that the right to water and sanitation remains the basis for health strategies that benefit the peoples of their respective countries (WHO, 2011a). International sources underline that access to adequate quantities of drinking water is a human right that is foundational for consumers' welfare and a precursor to many other rights (Gerber and Chen, 2011; MacIntosh, 2013; UN, 2002). Safe drinking water is one of the best public health investments (Hrudey, 2008).

The MDGs have since been improved by the 2030 Agenda for Sustainable Development, which recognises safe drinking water, sanitation and hygiene as an end in itself and a driver of progress on the Sustainable Development Goals (SDGs) adopted in 2015. SDGs are 17 universal goals agreed by United Nations (UN), with a vision to address poverty, hunger, inequality, climate change, environmental degradation, prosperity, and peace and justice and safe from the worst effects of climate change (UN, 2015). Goal Number 6 aims to ensure the availability and sustainable management of water and sanitation for all. Sustainable management will be promoted by increasing investment in the management of fresh water resources, ecosystems and sanitation facilities, and tackling water scarcity and water pollution in accordance with national circumstances and priorities. The targets for Goal 6 include:

- 6.1 By 2030, achieve universal and equitable access to safe and affordable drinking water for all

- 6.2 By 2030, achieve access to adequate and equitable sanitation and hygiene for all and end open defecation, paying special attention to the needs of women and girls and those in vulnerable situations

- 6.3 By 2030, improve water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally

- 6.4 By 2030, substantially increase water-use efficiency across all sectors and ensure sustainable withdrawals and supply of freshwater to address water scarcity and substantially reduce the number of people suffering from water scarcity

- 6.5 By 2030, implement integrated water resources management at all levels, including through transboundary cooperation as appropriate

- 6.6 By 2020, protect and restore water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers and lakes

- 6.A By 2030, expand international cooperation and capacity-building support to developing countries in water- and sanitation-related activities and programmes, including water harvesting, desalination, water efficiency, wastewater treatment, recycling and reuse technologies

- 6.B Support and strengthen the participation of local communities in improving water and sanitation management (UN, 2015).

Australia is considered to be at almost 100% in the provision of safely managed water services. Safely managed water services mean drinking water from an improved water source located on premises, available when needed, and free from faecal and priority chemical contamination (WHO/UNICEF, 2017). Australia's drinking water status is influenced by its adherence to Australian Drinking Water Guidelines 2011. The 2016 *Overcoming Indigenous Disadvantage* report identified that some challenges have been seen as contributing to continuing health outcomes disparities for remote Indigenous communities, such as poor water quality and limited access to safely managed water (Hall et al., 2017). One of the problems was the use of bore water, which may contain naturally high levels of microbial and chemical contaminants, making the water unpalatable and leading to preference for unsafe water sources and sugared drinks (Hall et al., 2017).

Neither the *Universal Declaration of Human Rights 1948* (United Nations General Assembly, 1948) nor the succeeding *International Covenant on Economic, Social and Cultural Rights* expressly acknowledges the Right to Water (Committee on Economic, Social and Cultural Rights, 2002). In 2010, however, the United Nations General Assembly unanimously adopted the non-binding *Declaration on the Human Right to Water* (UN, 2010). When elements of the right to water are tampered with, there is an elevated risk of communicable disease outbreaks (MacIntosh, 2013). Consequently, in 2011, the UN Human Rights Council passed a resolution calling on Member States to guarantee adequate funds for the sustainable delivery of water (UN, 2011).

In New South Wales, Australia, water utilities operate under guidance from NSW Health and NSW Department of Industry Water to ensure the safe and adequate drinking water supply at all times. Water utilities are required to develop a comprehensive Drinking Water Management System under the NSW *Public Health Act 2010* (NSW Government, 2010), including a catchment to tap risk assessment and operational plan. This approach is considered industry best practice and is a common approach used across Australia and around the world.

Drinking water quality needs to be regularly monitored for public safety (NHMRC, 2011; WHO, 2017). Drinking water safety is principally based on risk assessment to identify potential sources of contamination, the monitoring of water contamination parameters, checkpoints of identified potential risks and the establishment of effective management control systems (Rihova Ambrozova et al., 2010). Microbiological water quality is based on pathogen indicator monitoring (Ashbolt et al., 2001). Drinking water monitoring tests that barriers to contamination are operating efficiently (NSW Health, 2005).

This chapter presents a narrative literature review on published works about drinking water and recreational water microbiological safety, microbial risk management and consumer perceptions of drinking water in Australia for the period 1990-2018. International perspectives are included for comparison purposes. The chemical aspects of water quality are also briefly discussed as they relate to consumer perceptions and acceptability of the water supplies.

2.2 Search Terms

Drinking water; drinking water quality; drinking water quality assessment; safe drinking water; drinking water quality management; drinking water risk management; drinking water risk perceptions; and water quality perceptions.

2.3 Literature Search Method

A narrative review of the literature was conducted at the beginning of the research project with additions being made throughout the research period as new literature emerged. The James Cook University (JCU) library was used as the primary gateway to search ScienceDirect; PubMed; Scopus; Google Scholar and eJournal databases. The search was limited to journal articles and grey literature published in English. Initially, abstracts were reviewed, and if relevant to drinking water quality management and perceptions, full papers were sought and reviewed for relevance. Next, the "*ancestry approach*", in which references from key papers are systematically traced as secondary searches were used (Cooper, 1982). Targeted related articles (suggested articles in the primary search databases such as PubMed and ScienceDirect) were also used. Articles which were not accessible through the University library were sourced through the NSW Clinical Information Access Portal (CIAP). Figure 2.1 illustrates the search procedures followed.

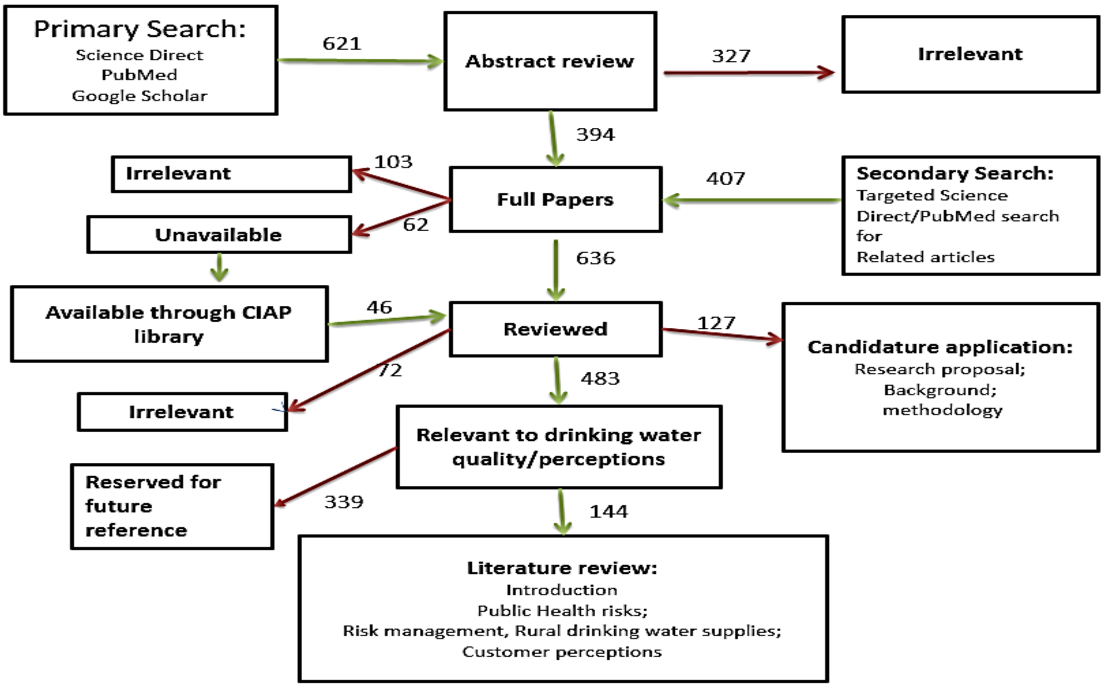


Figure 2.1 Search procedure

2.4 Inclusion Criteria

This review includes literature on:

- Interventions that focused on the public health effects of water quality;
- Studies with a focus on the microbial quality of treated drinking water;
- Studies/reports focusing on interventions on waterborne gastrointestinal disease outbreaks caused by drinking water;
- Studies focusing on drinking water perceptions; and
- Studies that were reported in English.
- Water-borne diseases are well-established public health risks (Huck and Coffey, 2004; Rowe, 1998). In this review water-borne disease outbreak is defined as the the occurrence of cases of a disease above what would normally be expected in a defined community, geographical area or season (WHO, 2018a).

2.5 Exclusion Criteria

This review excludes:

- Studies with a specific focus on interventions on untreated drinking water supply;
- Studies with a specific focus on interventions on the point of use treatments;
- Studies that focused on interventions based on computer modelling and health technology assessment; and
- Studies with specific focus on the chemical aspects of water quality.

2.6 Definition of Drinking Water

Safe drinking water provision is closely associated with health (Hunter et al., 2009). Microbiologically and chemically unsafe drinking water supplies cause disease outbreaks and death globally (Sobey, 2006). Delivery of "clean water for all" is dependent on informed individuals and communities and also upon policy and decision makers (Younes and Bartram, 2001). Communities may prefer their drinking water to be "clean" (Yasar et al., 2011), "safe" (Sobey, 2006) and "wholesome" (Hrudey et al., 2006; Hunter et al., 2009). These issues introduce the notion that individual knowledge, acceptability, and perception about water quality, the community's influence, and the policymakers' ability to regulate and deliver it, are important drinking water service determinants.

Safe drinking water should not pose any considerable risk to health even if consumed over a lifetime, including specific sensitivities that may ensue between human life stages (NHMRC, 2011; WHO, 2011a). The Committee on Economic, Social and Cultural Rights adopted General Comment 15 defining the right to safe, sufficient, affordable, acceptable and accessible drinking water for everyone in 2002 (Committee on Economic, Social and Cultural Rights, 2003). Drinking water must be free from pathogenic microbes and chemical hazards that present a threat to public health.

The Australian Drinking Water Guidelines (ADWG) 2011, further describes drinking water as clear, colourless, and well aerated, with no unpalatable taste or odour (NHMRC, 2011). Safe water should be free of pathogenic microorganisms, harmful chemical substances or suspended matter, and is aesthetically acceptable to the consumers (Miranzadeh et al., 2011; Rihova- Ambrozova et al., 2010).

Safety may not mean zero risks (Hrudey et al., 2006). To insist on an outright standard will result in all water supplies being considered unsafe, thereby rendering safety a hollow concept. Therefore, it is more useful to reflect on relative safety, since everyone has a different conception of safety from one risk to another. Safety is "a level of risk so negligible that a reasonable, well-informed individual need not be concerned about it, nor find any rational basis to change his/her behaviour to avoid such a small, but non-zero risk" (Hrudey et al., 2006, p. 949). Therefore, it is essential for the consumer to be well informed and accept the water before a supplier can proclaim the safety of its water supply.

Considering the current advanced technological capability for minimising risk, the safe drinking water concept means that the intended consumers perceive the water to be free from harm (Hrudey et al., 2006). A water supplier can face acceptability problems if water quality parameters important to customers (e.g. odour, taste, appearance) are blighted, or customer confidence is damaged even without public health risk (Hrudey et al., 2006). Some chemical substances can present both health risks and aesthetic problems. Hence, both maximum acceptable and aesthetic concentrations are upheld in water quality guidelines and regulations (NHMRC, 2011; Turgeon et al., 2004). The level of risk tolerated by an individual depends on beliefs and scientific knowledge (Jardine et al., 2003). When the microbial safety of the water is in doubt, NSW consumers are always informed through boil water alerts (WaterNSW, 2015).

Decisions on drinking water acceptability may conflict between objective (value-laden) and subjective (value-free) approaches (Hunter and Fewtrell, 2001). Expert knowledge results in value-laden, scientifically quantifiable values of acceptability such as the Australian Drinking Water Guideline's microbial value that *E. coli* should not be detected in any sample of water. Such definitions of acceptability aim at the reduction of public health risk through disease prevention that outweighs adverse impacts and resources required to reduce the risk to society.

The World Health Organization expresses microbial risk as to the yearly individual probability of infection for a given consumption of drinking water which enables the comparison of the importance of specific disease agent to public health (WHO, 2016). The US EPA (1989), WHO (2016) have used a Quantitative Microbial Risk Assessment (QMRA) approach to define acceptable risk. The QMRA is a framework that can be applied to quantify the required level of drinking water treatment needed to achieve a defined health outcome target proportional with the level of source water microbial contamination. The US EPA used QMRA as a measure of annual infection risk target to develop water treatment requirements for Giardia lamblia and enteric viruses in the Surface Water Treatment Rule (US EPA, 1989). The rule was subsequently changed to enhance pathogen removal capability for poor quality source waters to reduce *Cryptosporidium* infection in Surface Water Treatment Rule 2 (US EPA, 2006).

The WHO adopted the tolerable risk target (health outcome target) as a measure of acceptability dependent on disease burden called Disability Adjusted Life Years (DALY) (WHO 2004). The DALY aggregates the health impacts to give an inclusive measure of the burden of disease (Leder et al., 2012). A DALY is a product of years of life lost (YLL), years lived with a disability (YLD) due to the disease agent standardised by severity weights of the disease condition to the given population:

DALY = YLL x YLD (WHO, 2016b, Havelaar and Melse, 2003).

The DALY weighs and estimates the burden of disease for each disease agent, considering death as the most severe outcome. The DALYs approach combines quantity and quality of life, based on epidemiology and exposure data. The USEPA tolerable risk target is 10^{-4} DALY per person per year (US EPA, 2006). The proposed Australian Drinking Water Guidelines 2011's DALY for drinking water, currently under public consultation, is 10^{-6} which is also referred to as 1 µDALY (NHMRC, 2018a).

No level of risk may be acceptable to all individuals. The acceptable risk may be a political decision (subjective) and value-free such as the objectionable taste of the water. The acceptable risk is, therefore, dependent on what is acceptable to the general public and is a result of political bargaining between the utility and the community (Hunter and Fewtrell, 2001). The burden of disease is usually compounded by sociocultural, economic, environmental and political factors that can affect the acceptability of a drinking water supply (Havelaar and Melse, 2003). Therefore negotiation becomes important to determine a supply's acceptability notwithstanding the importance of the microbial water quality. The US EPA contends that the acceptability of risk depends on scientific data, social, economic, political and perceived benefits arising from the exposure to the disease-causing agent (US EPA, 2012).

2.7 Rural Drinking Water Supplies

Rural water suppliers have a duty of care as regards the safety of the water supplied, to minimise public health risk (Byleveld et al., 2009; Hrudey et al., 2006). Regular sampling of drinking water helps to ensure safe water supply (NSW Health, 2005). Rurality in relation to drinking water is often perceived to be synonymous with diseconomies of scale, limited technical and financial capacity, and aged infrastructure (Hrudey, 2008; Kot et al., 2011). The Australian water industry has a substantial skills shortage problem (AWA, 2009; Lemckert et al., 2014). The skilled personnel shortage may preclude smaller utilities from exploiting new technologies to meet all regulatory requirements (AWA, 2009). Rural utilities may find it difficult to obtain the lowest cost for the services available because they may be unable compete with larger metropolitan water utilities (AWA, 2009).

Cretikos et al. (2010) reported a greater likelihood of noncompliance with *Australian Drinking Water Guidelines* 2011 (ADWG) in rural drinking water supplies than in metropolitan supplies, due to diseconomies of scale rather than technical know-how. Most of rural drinking water supplies in Hunter New England serve small, economically disadvantaged, and least empowered communities, which are particularly vulnerable to the effects of faecal contamination (Cretikos et al., 2010). Therefore, rural drinking water supplies have greater potential to transmit waterborne disease (Sobey and Bartrams, 2003). A study carried out in rural Tasmania found that the main issues contributing to drinking water supply and safety problems were ageing and insufficient water supply infrastructure, lack of funds, staff turnovers, inadequate catchment management, and the effect of competing for land uses (Whelan and Willis, 2007).

Furthermore, some of the greatest risks are to those served by small public water supplies, non-transient, non-community types such as schools and recreational resorts with private water supply, and the transient non-community systems, such as those serving rest areas and campgrounds (Sobey, 2006). Although there are relatively few recognised outbreaks with public water supplies in Australia, there is a greater risk with private water supplies (Cowie and Byleveld, 2003; McAnulty et al., 1993).

2.8 Public Health Risks of Drinking Water

A risk can be described as the possibility of an event to cause harm (Alam, 2010). In NSW reticulated drinking water supplies have not experienced an outbreak of waterborne disease for more than a decade. It has been argued that person-to-person contact is primary cause of the diarrhoeal diseases in rural areas of NSW (Puech et al., 2001) However, the absence of waterborne disease outbreaks in a water supply system does not guarantee non-occurrence in the future (Rizak et al., 2006). Hellard et al. (2001) argued that although 15% of gastrointestinal infections in Melbourne could be attributed to drinking water, this was unlikely because of the high similarity in the distribution of gastrointestinal disease between the test and the control groups and the absence of reported waterborne outbreaks in Melbourne. Most of the isolated pathogens were chlorine-sensitive organisms which could have been controlled by chlorination. The *Cryptosporidium* isolated from participants were attributable to swimming pool related outbreak reported earlier (Hellard et al., 2000).

Experience shows that regional or rural drinking water supplies are prone to the risk of contamination and ongoing decline in their functionality and amenity, leading to waterborne disease outbreaks (WHO, 2012). Life-threatening infections can affect numerous people within a short time (Guzman-Herrador et al., 2015; McKay and Moeller, 2001). The World Health Organization has categorized water-borne diseases into groups, including:

- **True water-borne diseases** where water containing the disease causative agent, either a microbe or a chemical is ingested directly.
- **Water hygiene-related diseases:** personal hygiene is crucial in preventing such diseases as infectious diarrhoea, bacillary dysentery, infectious hepatitis, skin and eye infections and infestations such as trachoma scabies, ringworm, and conjunctivitis (Fewtrell et al., 2007).

Drinking water can serve as a medium to transmit diarrhoeal diseases such as cholera, dysentery, typhoid, salmonellosis, amoebiasis, cryptosporidiosis, and other bacterial, protozoal and viral intestinal diseases. In 2012, sanitation, hygiene, and unsafe water contributed 1.5% of the contributing global risks for disease, defined as disability-adjusted life years (DALYs) (WHO, 2016b). In Australia, the DALY attributable to diarrhoea caused by water, sanitation, and hygiene in 2012 was less than 0.1 per 100,000 capita (WHO, 2016b). The DALY for water quality alone is not known (AIHW, 2012 p.36), and no distinction has been made between public water supplies and untreated private water supplies.

Case-control studies in Australia suggest that contaminated swimming pools rather than drinking water may be the main mode of spread of enteric pathogens (Dale et al., 2010; Puech et al., 2001; Robertson et al., 2002). *Salmonella sp., Campylobacter jejuni, Cryptosporidium* and *Giardia* have been implicated in drinking water outbreaks in Australia (Dale et al., 2010). It is generally difficult to identify and categorise gastroenteritis outbreaks, due to scant epidemiological and microbiological evidence, resulting in the underestimation of waterborne diseases (Dale et al., 2010). Consequently, drinking water's contribution to waterborne diseases is not always obvious, although it may be a contributory factor to some foodborne infections, since it is used in food preparation and for ablution (Dale et al., 2010). No outbreaks have been attributed to public (reticulated) drinking water in New South Wales.

Rural water supplies are susceptible to pollution from human and animal faeces, which provide a favourable environment for the survival, proliferation and transmission of infectious agents (Guzman-Herrador et al., 2015; McKay and Moeller, 2001). Drinking water treatment regimens are compromised by chlorine-resistant microorganisms like *Cryptosporidium*, which are resistant to the drinking water disinfection concentrations, and require other advanced disinfection procedures (Funari et al., 2011). The need to improve drinking water risk management has long been recognised in regional NSW (Cretikos et al., 2010, Whelan and Willis, 2007).

Rural drinking water utilities are concerned with extreme weather events because they affect the drinking water infrastructure integrity, availability, quality, and treatment. Such issues impact on drinking water quality, reliability, legal compliance, customer perception, and budgets (Khan et al., 2015; Stanford et al., 2014). Extreme weather events affect water quality by increasing turbidity, organic matter, salinity and pathogenic microorganisms in the source water, thereby increasing the cost of water treatment (Khan et al., 2015). Small water supply systems are particularly vulnerable compared to highly technological metropolitan systems, due to low adaptability (Delpla et al., 2011). Ten case studies in Australia revealed that drinking water was severely compromised by infrastructure damage, cyanobacterial growth, conductivity, pH, and taste and odour problems exacerbated by multiple significant weather events rather than single events (Fitzgerald et al., 2014).

Some regional areas have poor water quality and a reduced capacity to supply drinking water due to the impacts of drought (Productivity Commission, 2011), resulting in substantial budgetary costs and severs water restrictions. Severe drought conditions in Australia have impacted on drinking water quality, affecting turbidity, taste, odour and colour (Wright et al., 2014). Water preservation measures may increase water age in distribution infrastructure, resulting in loss of chlorine residuals (Stanford et al., 2014). High temperatures cause increased loss of disinfectant residuals in distribution systems, resulting in increased pathogen risk and increased biofilm growth (Fisher et al., 2012). Generally, every 5º C water temperature increase doubles chlorine decay rates in treated water (Fisher et al., 2012).

2.9 Drinking Water Risk Management

Public health is focused on disease prevention. The adage “prevention is better than cure” and Benjamin Franklin’s axiom that “*an ounce of prevention is worth a pound of* cure” (Woolf, 2008) are worthy examples. When it was founded in 1953, the principal aim of the Nordic School of Public Health Public Health Programme was disease prevention (Polvsen and Borup, 2015). Safe and dependable drinking water is an essential public health service that a water supplier provides to a community (NSW Health. Office of Water, 2014). The ability to provide safe drinking water to consumers without fear of health risks is one of the main differences between developed and developing nations (Hrudey et al., 2006). Public health literature demonstrates that drinking water quality improvements minimise waterborne diseases and significantly improve health benefits when consumer exposure to poor quality water is low (deWilde et al., 2008).

Drinking water risk management has been described as a developmental cycle that starts with an incident, followed by an incident investigation to establish the root cause and ending with technical, operational or administrative corrective actions to prevent recurrence (MacGillivray and Pollard, 2008). The corrective actions may then be globally accepted resulting in changes to national legislation, codes, and standards (Alam, 2010; MacGillivray and Pollard, 2008). However, the developmental cycle has been replaced with the proactive source-to-tap risk management system, which eliminates the risks before incidents occur. This proactive risk management is the essence of the Drinking Water Management *Framework* promoted by the *Australian Drinking Water Guidelines 2011* (NHMRC, 2011).

One widely accepted tool for drinking water quality management is the document WHO *Guidelines for Drinking Water Quality* (WHO, 2017). The WHO guidelines offer global guidance for managing public health risk from hazards that compromise drinking water safety, and encourage the development and implementation of prevention strategies to ensure safe drinking water to protect public health (WHO, 2017). Each jurisdiction can then adapt guidelines which suit local conditions.

In line with the WHO guidelines, the *Australian Drinking Water Guidelines* 2011 (ADWG) provide detailed guidance on the management of rural drinking water systems (NHMRC, 2011). The ADWG recommend that small rural water systems follow a strict water management framework, although recognizing the practical limitations, particularly in very small systems (NHMRC, 2011). A preventive approach for drinking water supply systems is crucial because frequent monitoring may be difficult (Byleveld et al., 2008). Analysing the water supply system, identifying potential hazards and assessing risk are crucial (NHMRC, 2011). Developing and implementing a drinking water risk management plan, including standard operating procedures, monitoring, communication and corrective action plans, is emphasised (Byleveld et al., 2008).

The *Australian Framework for Management of Drinking Water* (*Framework*) outlines a Total Quality Management (TQM) approach for safe drinking water supply (Sinclair and Rizak, 2004). Instead of relying on routine compliance testing, the *Framework* emphasis on prevention, risk assessment, and the relevance of multiple barriers to ensure the protection of water quality to promote public health (Hrudey, 2004; Rizak et al., 2006; Sinclair and Rizak, 2004). The *Framework* is based on:

- A policy commitment at the highest levels of responsibility in the organisation;
- System risk assessments, analysis and risk management tools;
- Water quality data review;

- Hazard identification;
- Preventive/corrective actions measures, operational procedures;
- Verification of drinking water quality; and
- Incident/emergency response and research (Hrudey et al., 2006; NHMRC, 2011).

NSW Public Health Regulations 2012 (NSW Government, 2012) adopted the Water Safety Plans (WSP) concept to fulfil the obligations of the *Framework* and the *NSW Public Health Act 2010* (NSW Government, 2010). A vital element of an inclusive WSP is that water suppliers and stakeholders should have action plans in place to be able to react to a case of drinking water contamination or outbreak, to know when to advise consumers, and to determine how these warnings are to communicate with the customers (Byleveld et al., 2008). The *NSW Public Health Act 2010* requires drinking water suppliers to develop, implement and adhere to a drinking water management system (DWMS) (quality assurance program) as from September 2014. Risk assessment is fundamental in the development of the DWMS to distinguish between high and low risks (NHMRC, 2011) and to identify gaps and improvements to the management of the whole supply system (Byleveld et al., 2008). A DWMS comprises documents, procedures and supporting information for the supply of safe drinking water. The DWMS addresses the elements of the *Framework* and must be specific to the operations of a particular drinking water supplier. Record keeping is integral and provides retrospective proof of compliance in facilitating continuous improvement and enabling product traceability (Jayaratne, 2008). The DWMS must include a yearly review Action Plan for the water supplier's performance, and identify and address any underperformance and emerging issues. NSW Health, in conjunction with NSW Crownlands and Water, has published the *NSW Guidelines for Drinking Water Management Systems* to guide water suppliers on developing and implementing a DWMS (NSW Health. Office of Water, 2013).

Since the introduction of the *Australian Framework*, Australian States and Territories have supported the implementation by regional water suppliers, which has benefited rural communities by ensuring safer water supplies (Byleveld et al., 2008). NSW Health produced the *Private Water Supply Guidelines* (PWSG) in this regard (NSW Health, 2007). The guidelines summarise the ADWG, assisting small operators to comply with provisions for potable water supplies. The embracing of a risk management approach with a water quality management plan is key to the PWSG. The PWSG provide guidance on operator responsibilities and obligations, water quality, protecting water quality, water treatment, monitoring and checking the supplies and obligate public warnings. The PWSG are particularly useful for facilities that are not connected to reticulated supply systems, such as caravan parks, camping grounds, guesthouses, roadhouses recreational parks, marinas, mines and, schools (NSW Health, 2007).

NSW Health regulates drinking water quality in NSW. The introduction of the Drinking Water Monitoring Program since 2001 (NSW Health, 2005), the Aboriginal Communities Water and Sewerage Program (DPI, 2017), the amendments of the *NSW Public Health Act 2010* (NSW Government, 2010) and *NSW Public Health Regulations 2012* (NSW Government, 2012) and support for development and implementation of drinking water risk management plans (Byleveld et al., 2008) demonstrate NSW Health's desire to improve drinking water safety in rural areas. The NSW Health Drinking Water Monitoring Program, in particular, has greatly increased the monitoring of drinking water in regional NSW through clearer regulatory frameworks, a centralised ongoing sampling program, technical support and collaboration between local water suppliers and public health units (Byleveld et al., 2008).

Regular sampling and analysis testing of drinking water provide data on water quality, the efficiency of treatment regimens and the integrity of distribution systems. Direct analysis for pathogenic microorganisms is difficult because pathogens are intermittently present and in low numbers (Reynolds et al., 2008). For many years, water suppliers have therefore used microbial indicators to measure the microbial safety of drinking water (Yates, 2007). A microbiological marker, selected from a variety of microorganisms that has the power to represent the health potential of the water is an indicator of drinking water quality. However, no single microbial indicator organism or small set of indicators can successfully identify or predict the presence of all potential pathogens in a water supply system, but makes a connection between drinking water and health risk (National Research Council, 2006). The general characteristics of microbial indicators include:

- Should directly measure the process performance characteristics that are related to the effectiveness of the process in preventing or eliminating the hazards;
- Should be amenable to the setting of guideline or target values so that results can be responded to;
- Should provide warning of the process performance failures early enough to allow corrective action to be taken before unsafe water is supplied to the customers; and
- Should be of low cost and reliable to monitor, and where required, are amenable to on-line monitoring (NHMRC, 2011; WHO, 2011a).

Water suppliers assume that if indicator organisms are detected, then pathogenic microbes may also be present, and that if they are not detected, then the water is safe for consumption (Watkins et al., 2004). There is global agreement that *E. coli* are presently the most suitable microbial indicator of water faecal contamination (Committee on Indicators for Waterborne Pathogens, 2004). In line with this evidence, the ADWG recommend that *E. coli* be utilised as the primary indicator for microbial contamination of water in Australia. Drinking water utility performance verification is principally based on testing for *E. coli.* However, the Australian Drinking Water Guidelines 2011 recognise the limitations of end-point testing, and for this reason the *Guidelines* take a risk-based approach (the *Framework*) to ensure drinking water safety.

Research is crucial to ensure that drinking water risks are managed based on informed predictive capability (Hrudey et al., 2006). Research is a valuable tool for informing public health policy by identifying drinking water problems, offering preventive options and forecasting the likely effects of policy decisions by proposing evidence-informed recommendations (Humphreys and Piot, 2012).

In NSW boil water alerts are used to warn the public health when the water system integrity is compromised or in doubt (NSW Health, 2017c). Water utilities use public media like newspapers, radio and social media, letter drops, on-site warning signs and direct contact with vulnerable populations to advise consumers regarding the safety of drinking water (NSW Health, 2017c). From 2006 to 2008, 86% of boil water advisories in NSW resulted from birds and windblown matter entering reservoirs through reservoir or bird proofing defects (NSW Health. Office of Water, 2014). The other alerts were due to high raw water turbidity after floods, which the water supplier could not reasonably control. The breaches resulted in water supplies failing to comply with the microbiological water quality guidelines. Some lessons have been learned from the boil water alerts in NSW (Table 2.1).

Table 2.1 Lessons learned from boil water alerts in NSW 2006-2008 (NSW Health. Office of Water, 2014)

Practices	Lessons
Management	Institute regular preventative maintenance and calibration of chlorinators and associated equipment.
Disinfection	Ensure effective disinfection of the water.
	Continuous monitoring of the chlorination system to warn of any interruptions/failures of the chlorinator.
	Carry out chlorine demand tests on a regular basis and after a change in raw water characteristics; adjust chlorine dosage as necessary.
Storage	Ensure entry hatches to service reservoirs are secure, and that hatches are not left open; particular care is required if third parties (e.g., telephone companies) have been given access to reservoirs.
	Regular physical inspection is essential to detect and repair any design deficiencies or defects in the reservoir roof, wall or bird proofing of each reservoir. Early repairs must be compelled to correct any defects and prevent contamination of the stored water by birds, vermin or windblown material.
Free chlorine residual	Maintain a minimum free chlorine residual of about 0.2 mg/L throughout the water supply distribution system12 (including extremities where practicable).
Backflow prevention	Ensure appropriate backflow prevention devices are installed and are properly maintained (including any rainwater tanks used for toilet flushing).
Source monitoring	Monitor the raw water regularly and after storm events for evidence of changes in colour or turbidity.
	Chlorine demand tests should be carried out on a regular basis.
	Adjust chlorine dosing as necessary.

2.10 Consumer Perceptions of Drinking Water

Rural drinking water systems should be concerned about their operational excellence for building and maintaining trust and confidence among consumers (Alam, 2010). Consumer water quality risk judgment is influenced by observed variability of water quality, lack of control over the water supply, consumer satisfaction and lack of trust in the competence of governmental agencies involved in water supply (Syme and Williams, 1993). Perception of drinking water quality is important in determining preventive measures against water-borne diseases. Inaccurate perceptions result in communities not taking adequate risk management measures with resulting detrimental public health impacts (Yasar et al., 2011).

In Australia, risk perception and trust in water utility are strong determinants in the tolerability of drinking water (Ross, 2005). Knowledge is considered a predictor of water-related attitudes (Syme and Nancarrow, 2002). Consumer perceptions and aesthetic criteria should be respected when appraising drinking water supplies even if they do not harm human health (Bruvold, 1968; MORI, 2002; Warren, 1996; WHO, 2017a). Consumer perceptions are a complex interaction of diverse factors including:

- Organoleptic water properties;
- Risk perception;
- Dislike of water treatment chemicals;
- Reporting drinking water standards violations;
- Consumer's knowledge about source water characteristics;
- Consumer confidence in water suppliers;
- History of challenges concerning water safety;
- Mass media reporting on adverse water quality issues; and
- Demographics, biases and interactive associations (Doria, 2010; Syme and Williams, 1993).

Personal vulnerability, which is usually higher among sensitive groups and individuals suffering from debilitating diseases, can affect the perceived health risk of drinking water (Parkin et al., 2001). The belief that environmental health problems in the neighbourhood (e.g. mining) and low personal control over health risks exacerbates personal perceptions (Johnson, 2003).

Studies have shown that consumers reject drinking water largely due to concerns about their health (Noble, 1996; Turgeon et al., 2004; Younes and Bartram, 2001). Understanding consumers' perceptions improves water quality risk management, consumer satisfaction, water acceptability and risk communication (Doria, 2005, 2010). Similar issues have been reported globally. Water suppliers in Swedish rural areas are encouraged to be concerned about operational excellence for building and maintaining trust and confidence among consumers (Alam, 2010). In Hamilton, Canada it was found that community trust and support for water supply employees waned because of the Walkerton *E. coli* outbreak (Jones et al., 2007). Two pathogenic bacteria, enterohaemorrhagic *E. coli,* and *Campylobacter* were estimated to have caused some 2300 illnesses and seven deaths within a serviced population of about 5000 (Hrudey et al., 2003). Consumers became suspicious and sceptical about the competence and integrity of employees and the safeguards in the water system.

The perceived drinking water safety in affluent communities results in minimal motivation for positive cooperation (Hrudey and Hrudey, 2004; Jalba et al., 2014). The presence of efficient drinking water systems does not necessarily indicate that the systems are benefiting the consumers. Even though utilities strive to supply drinking water that always complies with standard safety guidelines, specific consumer expectations may not be met due to varying perceptions (Kot et al., 2011). Culture can influence drinking water perceptions by interfering with trust in water suppliers while risks are personalised or generalised in communities, and individual optimism and unconscious behaviour predominate (Doria, 2005; Jalba et al., 2010). Culture bestows socially structured illusions about the environment, which are then integrated into individual worldviews and influence people's understanding of the environment (Adelson, 1998; Jalba et al., 2010; Jones et al., 2007; Moggridge, 2010).

2.11 Recreational Water Microbial Risk

Notwithstanding continuous investment in sanitation and environmental protection by various legislations, waterborne disease outbreaks still pose significant risks to human health in developed countries (Bridge et al., 2010). The microbiological contamination of recreational waters by faecal waste and enteric pathogens is a major concern (Wheeler et al., 2002). The link between swimmers' health and the faecal contamination of recreational waterways has been well established (Cabelli, 1989). Contact or accidental ingestion of water during recreational activities can cause gastrointestinal diseases and infections of the ears, eyes, respiratory tract, nasal cavity, and skin (WHO, 2003). Epidemiological studies support the positive association between concentrations of enterococci and rates of swimming-related illnesses in fresh and marine waters (Wade et al., 2006, 2008). Faecal waste is regarded as the main source of enteric pathogens in water bodies because enteric pathogens are prevalent in faecal waste (Wade et al., 2006). Human faecal material is the most likely source of human specific pathogens (Yan and Sadowsky, 2007).

Contaminated recreational water can cause diseases, such as dysentery, diarrhoea, hepatitis A, giardiasis, cryptosporidiosis, campylobacteriosis and salmonellosis particularly in children, the elderly and the severely immunocompromised (WHO, 2003, NHMRC, 2008). Gastroenteritis and haemolytic uremic syndrome have been associated with water bodies containing *E. coli* O157:H7 (Bitton, 2011). Protozoa, especially *Cryptosporidium* and *Giardia*, that causes debilitating enteric diseases are common in Australia. Swimming in dams, rivers or lakes in NSW has been associated with cryptosporidiosis (Puech et al., 2001). Loganthan et al. (2012) found that recreational water catchments which allowed swimming and camping showed a predominance of *C. hominis* compared to non-recreational catchments which had a higher prevalence of *C. parvum*. Notification data suggest environmental factors are important predictors of these diseases (Lal et al., 2015).

Otitis externa, otitis media due to *Pseudomonas aeruginosa and Staphylococcus aureus infections* have been associated with swimming in freshwaters even where faecal indicator concentrations were considered acceptable (NHMRC, 2008). *Mycobacterium ulcerans*, skin ulcers in freshwater swimmers (WHO, 2003). Cases of *Naegleria fowleri* infection causing primary amoebic meningoencephalitis (PAM) have occurred in Western Australia, South Australia, Queensland and New South Wales (Miller et al., 1982; Dorsch et al., 1983; Trolio et al. 2008). Three deaths in children associated with recreational activities with bore water, a farm dam and reticulated water have been reported in Queensland (Nicholls et al., 2016). The route of infection is intra-nasal and associated with bathing rather than ingesting water. *N. fowleri* can potentially occur in any body of warm (25-46°C) fresh water, including lakes, rivers, dams, water supply bores, hot springs, waterholes, tanks and pipelines and poorly maintained swimming pools (Water Research Australia, 2016; NSW Health, 2017).

Cases of primary amoebic meningoencephalitis *(Naegleria fowleri)* from recreational water has been reported in the USA (Capewell et al., 2014). Between 1937 and 2013, there were 142 cases of *Naegleria fowleri* infection in the US with only three survivors (Capewell et al., 2014). Most victims were male children (median age about 12 years), who are more likely to engage in diving and vigorous play activities in water and were associated with recreational activities in natural surface freshwater bodies. While enteric viruses are also widely believed to be the main cause of recreational water illnesses (WHO, 2003), studies have neither incorporated methods to confirm their aetiologies nor have they enumerated them (Boehm et al., 2009).

Typical sources of faecal contamination include sewage outfalls, stormwater discharges, riverine discharges, bather shedding and animal faecal material (NHMRC, 2008; WHO, 2003). Rainfall events have been strongly associated with elevated microbial levels in water bodies (Cho et al., 2010). Runoff, generated by storms, or after urban activities like car washing, irrigation, and agricultural activities, can sometimes contain extremely high concentrations of enterococci. These levels can surpass concentrations measured in raw sewage (Olivieri et al., 2007; Reeves et al., 2004). Elevated microbial levels in recreational water bodies may pose health risks to bathers when water is ingested. Respiratory, ear, eye, and skin infections can also be acquired from direct water contact activities such as swimming. Rainfall events of 5mm or more have strongly been associated with elevated microbial levels in various sampling sites along the Swan and Canning Rivers, Western Australia (WA) during five consecutive bathing seasons in November 2010 to April 2015 (Gunady et al., 2016). Enterococci levels between 201 to 500 MPN/100 ml were associated with rainfall ranging from 3 to 21 mm, enterococci values between 501 to 700 MPN/100 ml were associated with rainfall ranging from 9.4mm to 30mm, and elevated enterococci levels over 700 MPN/100 ml were associated with rainfall ranging from 12 to 35 mm (Gunady et al., 2016).

2.12 Recreational Water Microbial Risk Management

The WHO Guidelines describe an assessment approach based on a combination of sanitary inspection (to identify susceptibility to faecal influence) and microbial water quality assessment (WHO, 2003). Sanitary assessments are based on identifying all potential sources of faecal pollution, although human faecal pollution will tend to drive the overall sanitary inspection category for an area. Microbial water quality assessment is used to categorise recreational water quality based on measurements of the 95th percentile intestinal enterococci densities (WHO, 2003).

Microbial contamination levels are determined by use of indicator faecal bacteria (WHO, 2003; Ferguson et al., 2005). The WHO, US EPA and NHMRC recommend the use of enterococci as the preferred faecal indicator in marine and fresh recreational water analysis (NHMRC 2008; US EPA, 1986; WHO, 2003). Enterococci are used as indicators of environmental contamination because they are found in high concentrations in faeces, and exposure to enterococci has been found to have a clear dose-response relationship to swimmers' disease outcomes (Boehm & Sassoubre, 2014; WHO, 2003). Enterococci are preferred because of their ability to mimic many pathogens in recreational waters (US EPA, 2012). The presence of enterococci in fresh water is regarded as evidence of point or nonpoint source pollution and resuspension from environmental reservoirs, because freshwater habitats do not support the growth of enterococci (Byappanahalli et al., 2012).

A limitation of faecal indicator bacteria monitoring is that they are not believed to be conservative indicators for some of the most important sewage-derived pathogens, including a number of enteric viruses (Field and Samadpour, 2007; Fujioka et al., 2015). When the source of enterococci contamination to surface waters is not fecal, their presence may not indicate a health risk (Boehm and Sassoubre, 2014). Indicator organisms from non-faecal sources may result in water bodies being incorrectly classified as contaminated when the public health risk is not increased (Boehm et al., 2009). Faecal indicator bacteria concentrations may abruptly vary before monitoring results can be obtained, resulting in contaminated waters being left open to swimming when they should be closed. Therefore, there is a need to measure supplemental indicator organisms. These are indicative of risk for a wide array of human pathogens, and their monitoring would provide better protection of public health (Fujioka et al., 2015). Other sewage-specific markers have been identified including *C. perfringens*, various bacteriophages, Bacteroides, as well as human enteric viruses (Boehm et al., 2009; Fujioka et al., 2015). Sources of enterococci in recreational waters include sewage, agricultural and urban runoff, storm water, direct input by animals via defecation, bather shedding, boats, plant debris (for example, wrack), polluted groundwater, soils, sediments, and sands.

The WHO guidelines used the concept of grading recreational water bodies according to the suitability for recreational use based in levels of contamination. The grading uses a classification matrix of a sanitary inspection category (evidence for the likely influence of faecal material) and a water quality assessment category (95% percentile count of faecal indicator bacteria) as recommended in the WHO guidelines (WHO, 2003). The applied sanitary categories are ‘very low’; ‘low’; ‘moderate’; high’; and ‘very high’. The microbial water quality assessment categories are “A” (≤40 cfu/100mL), “B” (41-200 cfu/100mL), “C” (201-500 cfu/100 mL) and “D” (>500 cfu/100 mL). The combination matrix for sanitary risk assessment and microbial risk assessment gives the overall water quality grading of ‘poor’, ‘fair’, ‘good’ and ‘very good’ grades (Table 2.2). USA EPA recommended that a monthly geometric mean water quality indicator enterococci concentration be less than 33 cfu/100mL for a 30 day mean and 61 – 151 cfu/100 mL as a single sample reading for fresh water full-body contact beaches. It should not exceed 61 CFU/100 mL and 35 cfu/100mL for a 30 day mean and 104 – 501 cfu/100mL for a single sample for marine waters (Hrudey and Hrudey, 2004. p. 81-380; US EPA, 2012).

In Australia, recreational water safety is managed by the Guidelines for the Management Risks in Recreational Water 2008 (NHMRC, 2008) which have adopted the WHO guidelines. The guideline stated that “Preventive risk management practices should be adopted to ensure that designated recreational waters are protected against direct contamination with fresh faecal material, particularly of human or domesticated animal origin”. The guidelines primarily focus on local assessment and management of hazards and factors that may lead to hazards, considering the health and wellbeing benefits, and local economies that rely on water-associated recreational activities. The guidelines encouraged the development of local monitoring programs that provide real-time indication of water quality, particularly local environmental influences and numerical levels of microbial contamination. Such information is then used to:

- Classify beaches to support informed personal choice;
- Provide on-site guidance to users on the relative safety of the water;
- Assist in identifying and promoting effective management interventions; and
- Provide a basis for regulatory requirements, and an assessment of compliance with such requirements (NHMRC, 2008).

The use of a range of categories instead of a simple pass/fail approach, supports the principle of informed personal choice and allows the setting of practicable improvement targets for high-risk areas, rather than an "across the board" target which may result in less overall health gain (NHMRC, 2008; WHO, 2003). The assessment matrix enables authorities to decide on appropriate management actions and respond to contamination incidents. It also provides incentives for local rectification actions, and supports the publication of advisory notices (warming signs) to support informed individual choice.

Table 2.2 Classification matrix for faecal pollution of recreational water environments by combining sanitary inspection and microbial assessment categories (NHMRC, 2008).

		Microbiological Assessment Category (95th percentiles - intestinal enterococci CFU/100 mL)			
		A <40	B 41–200	C 201–500	D >500
Sanitary Inspection Category (susceptibility to faecal influence)	Very low	Very Good	Very Good	Follow up	Follow up
	Low	Very Good	Good	Follow up	Follow up
	Moderate	Good	Good	Poor	Poor
	High	Good	Fair	Poor	Very Poor
	Very high	Follow up	Fair	Poor	Very Poor

To facilitate and standardise the process, a Microsoft Excel template (the EnteroTester) has been developed in order to generate workbooks that estimate the infection risk (according to formula used in the above guidelines) for any given enterococcal distribution, and calculate a 95th percentile standardised to that of the reference distribution with the same risk (Lugg et al., 2012). A similar statistical decision support tool 'Enterosis A' was recently developed in order to facilitate the analysis of microbial water quality data for the purposes of classifying recreational waterways in south-east Queensland (Xie et al., 2015). Other approaches, such as the use of a Tweedie distribution have also been proposed (Patat et al., 2015).

2.13 Discussion

Waterborne disease outbreaks often result from system management failures - particularly inadequate, interrupted, or intermittent treatment (Percival and Williams, 2014). Drinking water disease outbreaks demonstrate known deficiencies in drinking water guidelines and supply systems, and the failure of water utilities to abide by the treatment protocols (Craun et al., 2010). Hence the need for the implementation of preventive risk management frameworks and regular drinking water data analyses to identify potential problems in water supplies. Measurement of illnesses caused by contaminated drinking water is challenging because of the difficulty in ascertaining a causative link between consumption of the water and disease outbreak (Dods and Copes, 2006). Such illnesses are usually blamed on food prepared with the contaminated water or handled by a food handler who cleaned his hands with the water (Poullis et al., 2005).

Drinking water quality monitoring is necessary to ensure safe water. The review did not find any literature discussing the impact of regular drinking water monitoring on drinking water quality and gastroenteritis. The grey literature may contain information that could assist public health officials in making drinking water-related decisions (Dods and Cope, 2006). Drinking water disinfection is an effective means of reducing water borne illness. Therefore, monitoring of pathogenic indicator microorganisms as a test to verify adequacy of preventive measures, should have an impact on water quality management and enteric disease prevention. The ADWG encourage:

- The development and implementation of operational monitoring plans;
- Identification of the parameters and criteria used to measure management effectiveness;
- Ongoing review and interpretation of results to confirm operational performance; and

- Detailing strategies and procedures corrective actions in case of non-compliance (NHMRC, 2011).

Some institutions like the US. National Centre for Disease Control (CDC) have used disease surveillance data to identify the etiologic agents associated with waterborne outbreaks (Craun, et al., 2010). Consumers tend to know about the safety of their water when something tragic happens, as in the Walkerton incident (Hrudey et al., 2006). The potential health risks associated with reticulated drinking water previously described in NSW have not been described in rural Hunter New England, although Cretikos et al. (2010), Li et al. (2009) and Miles et al. (2011) have reported on the general drinking water safety in regional NSW.

Surveillance data provides critical information about the existing disease burden, the justification for funding, help monitor the impact of water safety programs and assist public health workers in making informed decisions on policy (Nsubuga et al., 2006). Surveillance data is also utilised to determine research priorities to lobby for enhanced water quality regulations (Lee et al., 2002). However, the absence of a disease outbreak does not guarantee water safety. Similarly, the non-detection of indicator organisms in a water sample does not present ample guarantee for absence of all pathogenic microbes (Smeets et al., 2010). The concept of using disease surveillance to establish water system deficiencies does not obviate the need for performance and verification monitoring of drinking water quality. Waterborne disease is severely underreported and aetiologies not often identified (Ford, 1999). Disease surveillance data should be used to complement performance and verification monitoring data on drinking water quality.

Surveillance is a reactive approach to identify and manage public health risks in order to prevent disease outbreaks. Drinking water safety means much more than the lack of disease outbreaks, rather than the absence of disease altogether. The absence of illness entirely should be the preventive philosophy of public health. The literature notes that global waterborne disease outbreaks occur regularly and are mostly the cumulative impact of separate minor events, which, taken individually, may be relatively insignificant (e.g. Hrudey, 2004). The significance of the collective impact of individual events and the significance of taking preventive approaches to the provision of safe drinking water is highlighted. Therefore, it is essential to maintain water quality data surveillance in conjunction with surveillance of implementation and application of risk management plans and disease surveillance data.

The key to ensuring clean, safe and reliable drinking water is to understand the journey of the supply from the source to the consumer's tap and utilising the multibarrier approach

(WHO, 2011a). Justice O'Connor identified the use of multiple barriers in order to prevent contamination from affecting drinking water (O’Connor, 2002). The multi-barrier approach is an integrated system of procedures, processes and tools that collectively prevent or reduce the contamination of drinking water from source to tap, in order to reduce risks to public health (SDWF, 2019). A multi-barrier approach means taking actions at critical points in the delivery chain to prevent contamination of sources of drinking water, using adequate water treatment and distribution systems, water testing and training of water managers incorporating surveillance of implementation and application of drinking water management plans (O’Connor, 2002; SDWF, 2018; WHO, 2011b). The multi-barrier approach recognizes the inter-relationship of health and envir onmental issues, and encourages the integration of efforts to improve public health with those that also protect the natural environment (Federal-Provincial-Territorial Committee on Environmental and Occupational Health, 2002).

A multi-barrier approach is the epitome of “best practice”, which is demonstrated in the statutes and guidelines of many jurisdictions. Globally, it is agreed that source water protection (SWP) provides safe drinking water by preventing the contamination of untreated water at the source (Rawlyk and Patrick, 2013). The basis of SWP is that it is cheaper and more effective to prevent contamination at the source, than to expend more resources responding to the contamination (Simpson and De Loë, 2014), considering the high risks of contamination, as witnessed through drinking water disease outbreaks (O’Connor, 2002; Hrudey and Hrudey, 2004). The underutilisation of SWP is a major contributor to poor water governance, especially in small communities (Manrahan and Dosu Jr., 2017). In Canada, for example, there is a widespread failure to monitor source water with only 15% of Local Service Districts reporting regular monitoring of source water (Vodden and Minnes, 2014).

Drinking water safety is often indicated by the number of samples that fail sampling tests. This approach does not consider the acceptability of the microbiologically and chemically safe water. Moreover, a single pollution incident may result in a disease outbreak. This review identified the multi-barrier paradigm as the most effective approach to water quality protection. However, no reference has been made to link consumer perceptions and cultural values to the multi-barrier model. Source protection, adequate treatment, and safe distribution can prevent water contamination, but if the intended consumer rejects the supply due to negative perceptions of the water or through cultural impediments, this will mean nothing. Consumer behaviour needs to be considered as an important component of the multi-barrier paradigm to enhance total quality control. Moreover, the literature in this review only discussed perceptions regarding aesthetic values (taste, odour and colour), without considering the cultural attributes of the consumers.

Changing people's behaviour is very challenging. Experience, other influences, and cultural beliefs may be stronger motivators than personal and family health, especially where poor health is the norm (Institute of Medicine. Committee on Health and Behavior, 2001). Byleveld et al. (2008) discussed the critical role of risk communication in water quality management plans. These management plans should include responding to contamination events, issuing clear guidance on when and how to advise consumers and how the advice is communicated to consumers. Such communications may be meaningless if the intended consumer does not utilise the water due to other reasons than the water quality. Thus, there is need to understand consumers' behaviours before any communication is made. Participatory activities involving consumers to provoke debate are effective methods of communicating key messages to help the community envisage their health problems (Waterkeyn and Cairncross, 2005). Participatory approaches were first utilised in the water sector in the 1980s to mobilise communities (Srinivasan, 1990). Consumer participation in the management of public drinking water has not been discussed in the literature except around consumer consultation.

2.14 Conclusion

This review reveals a pattern which is consistent with the current drinking water management approach presented by the WHO and *Australian Drinking Water Guidelines* and epitomizes the legislative potential that could be used to efficiently improve drinking water quality. Drinking water quality verification monitoring is an integral part of the management plan to demonstrate that the multi-barrier prevention process is functioning effectively. However, verification monitoring should be used to complement operational monitoring that confirms the effectiveness of each component of the multi-barrier process. Operational monitoring minimises the probability of contaminants spreading into the system to consumers before they are detected. The water supplier is legally and morally responsible to provide safe water that is satisfactory physically, chemically and aesthetically to customers.

A key challenge for many water utilities is management of small water supply systems due to the lack of the "*economy of scale"*. Small communities lack adequate infrastructure afforded by large metropolitan cities although they are more vulnerable to contamination, which presents the public health risks of waterborne disease outbreaks. Despite improvements in drinking water treatment and regulatory interventions, rural areas in developed countries still experience waterborne disease outbreaks. Establishing the risks posed by drinking water provision in rural areas is crucial to supporting the development of responses directed towards mitigating public health risk. The ADWG acknowledge the need for the consideration of diversity in regional and local economic, political and cultural situations.

This literature review has highlighted gaps in the knowledge and understanding of what motivates consumer perceptions of water quality, and underlines the need for further research. Consumer experiences and views of drinking water quality and factors which influence perceptions need to be investigated to inform future policies about drinking water quality. Even when there is no public health risk, a discoloured supply or unusual odour or taste can result in consumers being concerned about their health.

There are relatively few recognised outbreaks in areas supplied by public water utilities in Australia. However, success may breed complacency. A few days of disrupted or contaminated water supply may undermine the health gains from the provision of safe drinking water for years. This literature review has confirmed that effective risk management, including continuous improvement and consumer perceptions, is crucial to achieve and maintain safe drinking water. Therefore research is necessary as a component of sustainable drinking water quality surveillance in rural areas of Hunter New England. Preparedness means maintaining effective disease surveillance systems that ensure noncompliance is reported and dealt with promptly and appropriately. Drinking water quality monitoring is a vital component of the surveillance system, in which the environmental health sector should play a pivotal role by placing value on drinking water quality research that explores not just regulatory and guideline compliance, but consumer attitudes, beliefs and perceptions about the water supply.

Chapter. 3 Drinking Water Safety in Rural Hunter New England, NSW, Australia 2001-2015

Plate 3.1 Water source pollution - cattle grazing and recreation at drinking water sources in regional Hunter New England (Personal collection)

3.1 Overview

There is an increasing global interest in improving and evaluating healthcare delivery systems in order to add value to public health (Fredriksson et al., 2015). Collecting service monitoring data about compliance with performance guidelines, procedures and outcomes is instrumental in improving the quality of public health delivery (Adami and Hernan, 2015). This chapter utilises routinely collected data to examine drinking water sampling adequacy and *E. coli* detections in rural Hunter New England during the period 2001-2015, inclusive. The objective is to determine the level of compliance with the NSW Health Drinking Water Monitoring Program (NSW Health, 2005) and to assess the potential health risk consumers are exposed to as per the Australian Drinking Water Guidelines 2011 (NHMRC, 2011). The routinely collected data is stored in the Program's central electronic database, the NSW Drinking Water Database (Database). The Program assists NSW Health and public water utilities in rural NSW to verify the quality of drinking water management. The database, established in 2001, has collected over one million water testing results state wide.

Routinely collected data obtained for performance monitoring purposes is increasingly used for research (Benchimol et al., 2015; Ramsberg and Platt, 2017). Researchers often refer to the use of routinely collected service data as "data mining" (Bloomrosen and Detmer, 2010). Data mining exploits the existing infrastructure that supports service delivery, in order to generate new knowledge and evidence that can impact research and public health service delivery (Bloomrosen and Detmer, 2010). Existing electronic data can be utilised to obtain service outcome information and to facilitate improvements and policy revisions. Policy revisions are necessary to reshape public health service delivery to meet emerging needs in line with practitioner experience. Effective use of routinely collected data can promote a sustainable health delivery system that provides safe and efficient health services for all Australians (Australian Digital Health Agency, 2018).

3.1.1 Background

Drinking water quality risk management is closely associated with the demonstration of due diligence in the control of water borne disease outbreaks (Miller et al., 2009). Due diligence is the prevention of reasonably foreseeable harm through:

- Assessment of the predictable risks to the customer from water source to the tap;
- Appropriate procedures for managing the risks in the applicable regulatory and legislative context;
- Verification of compliance with established guidelines and standards;
- Continuous review of activities to actively find out and incorporate new knowledge; and
- Applicable contingency planning (Miller et al., 2009).

Drinking water monitoring to consistently improve understanding of water supply systems and knowledge of the current risks is integral to drinking water risk management (Rizak and Hrudey, 2007; WHO, 2011a). Drinking water quality can deteriorate in the distribution system even when there are no apparent concerns about water management (Rihova Ambrozova et al., 2010). Despite adequate treatment, drinking water quality is often variable, and can only be appropriately maintained if monitoring is regular and frequent (WHO, 2011b). Drinking water monitoring improves service delivery to enhance public health, and economic, and human rights benefit from the improved water supply (Howard and Bartram, 2005). Drinking water quality verification monitoring should be regarded as the final check proving that, overall, the barriers and preventive measures implemented to protect public health are working effectively (NHMRC, 2011).

Reliance on compliance monitoring of treated water tends to promote a reactive management style (Sinclair and Rizak, 2004). Corrective actions are generally initiated after monitoring exposes that prescribed levels have been exceeded, and usually after consumers have already received the contaminated water (Sinclair and Rizak, 2004). However, compliance monitoring can verify that preventive measures are effective, rather than acting as the primary means of protecting public health (Sinclair and Rizak, 2004). This study supports such verification monitoring as a means of improving preventive measures to safeguard public health.

The range of pathogenic microbes is extensive (Yates, 2007). Monitoring for specific pathogens is complex, expensive, time-consuming, and may not always detect their presence hence the use of indicator organisms as markers for the presence of faecal contamination and the possible presence of microbial pathogens (NHMRC, 2011; Yates, 2007). Indicators are quantifiable characteristics that can serve to measure the effectiveness of processes in controlling specific hazards or groups of hazards (NHMRC, 2011). Indicators do not prove the health effect but make a connection between drinking water and health risk and help to verify the adequacy of preventive measures in the system

(Ashbolt et al., 2001; Edberg et al., 2000). Faecal indicator bacteria are numerous in faeces and serve as indicators for the possible presence of faecal contamination and, by inference, enteric pathogens (NHMRC, 2011).

The Australian Drinking Water Guidelines 2011 (ADWG) and WHO guidelines recommend *E. coli* as the microbial indicator bacterium as currently the best verification indicator available for faecally related microbial quality of drinking water (NHMRC, 2011; WHO, 2011) although there are limitations. *Cryptosporidium* oocysts, for example, may survive chlorine disinfection and may be present in the absence of *E. coli*. Pipes et al. (1987) showed that coliform concentrations in a drinking water sample were not stable and not reproducible hence the introduction of the present/absent and most probable number to approach to water quality testing. The detection of *E. coli* in treated drinking water indicates the presence of faecal pathogens (Edberg et al., 2000; WHO 2011). The *E. coli* presence may be because the source water was contaminated, and the ineffective treatment of water, or because the water was contaminated in the distribution system after treatment (National Research Council, 2006). The presence of faecal pathogens is thus assumed, and consequently, water is regarded as a significant risk to public health. Therefore, all *E. coli* detections must be promptly investigated and corrective action implemented, particularly the revision of the risk management systems (NSW Health, 2016a). NSW Health provided the NSW Health Response Protocol for Managing Pathogen Risks, updated in 2018 to assist water utilities (NSW Health, 2018).

There have been no recent recorded waterborne disease outbreaks due to public drinking water in NSW. The strict adherence to risk management, frequent water testing and improved risk communication between suppliers and regulators, e.g. urgent follow up on noncompliance (Byleveld et al., 2016), has contributed to the absence of outbreaks in NSW. The more samples tested, the higher the probability of real findings in a set of the smallest P-values of a predefined size (Vsevolozhskaya et al., 2017). Water utilities need to find the balance between verification monitoring (sampling adequacy), operational monitoring and effective operation of critical control points (CCP). A CCP can be defined as an activity, procedure or process at which control can be applied and which is essential to prevent, eliminate or reduce a hazard to an acceptable level (NHMRC, 2011). Through continuously maintained CCPs, there can be greater confidence in the safety of the supply. Environmental health practitioners and water utilities must anticipate harm before it occurs and provide measures to protect against potential harm even if the probability cannot be measured accurately by the existing science (Crawford-Brown and Crawford-Brown, 2011).

3.1.2 NSW Health Drinking Water Monitoring Program

In NSW, the Chief Health Officer has the power, under Section 22 of the *NSW Public Health Act 2010* (NSW Government, 2010), to issue advice for the benefit of the public, concerning the safety of drinking water and any possible risks to health involved in the consumption of that water (NSW Health, 2005). NSW Health established the Drinking Water Monitoring Program as a measure verify that barriers to contamination are working effectively, (NSW Health, 2005). The Program provides guidance on sampling adequacy and response protocols in the event that contamination is detected. The program supports local water utilities to monitor drinking water with free-of charge routine laboratory tests of drinking water samples for *E. coli* and a range of inorganic chemical and physical characteristics. The Program encourages water utilities to implement at least seven elements of the Framework for Drinking Water Quality Management of the ADWG (NHMRC, 2011)

- Element 2: Assessing drinking water supply system.
- Element 5: Verifying drinking water quality.
- Element 6: Managing incidents and emergencies.
- Element 7: Employee awareness and training.
- Element 9: Research and development.
- Element 10: Documentation and reporting.
- Element 11: Evaluation and audit.

Samples should be collected at points within the distribution system that are representative of the quality of water supplied to consumers (NHMRC, 2011). NSW Health, in consultation with the water suppliers, predetermines the minimum sample numbers for each water supply system. The WHO guidelines and the ADWG recommend sampling at least once a week (NHMRC, 2011; WHO, 2011b). The recommended sampling frequency needs to be balanced against the logistics of collecting the samples, the risk profile for the supply, and the risk mitigation processes that are operating on the supply especially for small remote water supply systems. With remote water supply systems, regular physical inspections and operational monitoring are more beneficial to ensuring water quality than infrequent *E. coli* sampling.

The minimum sample numbers are based on the minimum sampling frequency recommended in the ADWG (NHMRC, 2011) and adopted in the Program, the population served, and the complexity of the system (Table 3.1). The complexity of the supply system may result in greater or fewer samples allocated than the number obtained by the method recommended in Table 3.1. Annually, NSW Health issues each water supply system with sufficient barcoded sample labels (Table 3.1) for the recommended number of drinking water microbiological quality monitoring tests (NSW Health, 2005).

Table 3.1 Basis for allocating microbiological sample numbers in regional NSW (NSW Health, 2005)

Discrete Systems (supplying a single town and surrounds)	
Supply population	**Recommended minimum number of samples**
<100	12 samples per year (1 per month)
<500	26 samples per year (1 per fortnight)
500 – 5000	52 samples per year (1 per week)
5000 – 100 000	52 samples per year (1 per week), plus one additional sample per month for each 5000 above 5000
>100 000	Six samples per week, plus one additional sample per month for each 10 000 above 100 000
Complex Systems (supplying more than one town and surrounds)	
<1000	12 samples per year (1 per month)
1000 – 5000	26 samples per year (1 per fortnight)

According to the Program (NSW Health, 2005), water quality sampling adequacy depends on the number of samples tested. For maximum sampling adequacy the water utility should submit the predetermined number of samples in the specified period for testing by the NSW Health Forensic and Analytical Science Laboratories or any other National Association of Testing Authorities accredited laboratory. Results obtained from the Program are stored in a central, web-based Database (NSW Health, 2017a).

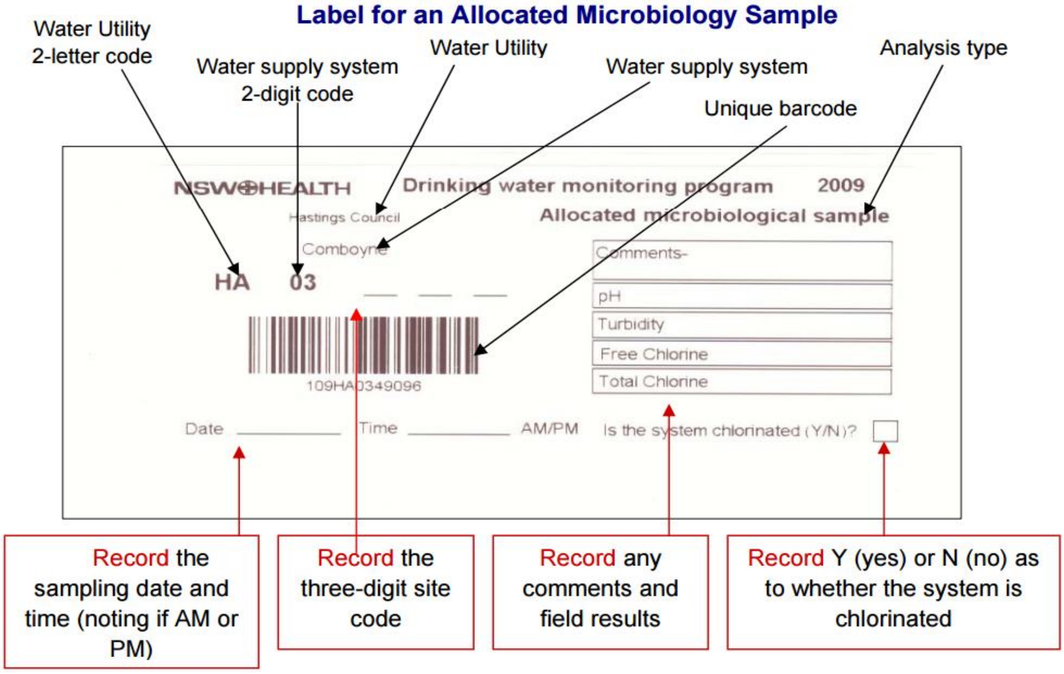


Figure 3.1 Illustration of a drinking water microbiological sampling label with added Instructions NSW Health 2001-2015 (DAL, 2010)

3.2 Method

Routinely collected drinking water data was obtained from the (Database). Monthly and annual water sampling adequacy was determined by expressing the collected samples as a proportion of the expected sample allocations for the respective period. *E. coli* detections for each water supply system were expressed as proportions of the collected samples for the respective periods. The water sampling adequacy and its association with *E. coli* detections and the interface between various associated water quality factors were explored.

The water supply systems were grouped into the following four population size groups irrespective of the complexity of the supply system:

- Group 1: systems serving less than 100 people
- Group 2: systems serving 100 – 499 people
- Group 3: systems serving 500-4999 people
- Group 4: systems serving more than 5000 people.

The supply systems were also grouped according to the primary water sources:

- Group 1: Dams
- Group 2: Rivers

- Group 3: Groundwater (Bores)
- Group 4: More than one source

The data were then analysed regarding:

1. Monthly and yearly sampling adequacy from 2001 to 2015 by water supply system, water source and population served,
2. Monthly and annual *E. coli* detection rates by water supply system, water source, treatment type, population served,
3. The trends in water quality monitoring over time (monthly, seasonally, yearly)
4. Relationship between sampling adequacy and *E. coli* detection.

Data quality assurance was incorporated into all stages of the study, from data collection and analysis to reporting. Integrity checks, stakeholder reviewing and duplicate analysis were utilised to ensure that the database reflected the correct information. Additional checks of the data were made by the database managers, who also helped to collect the data drafts.

The findings were discussed with the NSW Health Water Unit management. The new legislative requirement of the *NSW Public Health Act 2010* to implement a quality assurance program was a major change for some utilities, NSW Health gave utilities until 1 September 2014 to establish their programs (Byleveld et al., 2016). A decision to assess the development and implementation of drinking water management systems (DWMS) was made. NSW Health undertook to contract drinking water engineering and scientific experts to assist utilities in need.

Meetings were held with the respective water utility managers to discuss the results, possible causes and implications for water quality of the identified shortfalls in sampling adequacy and *E. coli* detections. The requirements of the *NSW Public Health Act 2010* (NSW Government, 2010), particularly the requirement for DWMS, including regular quality testing, were discussed.

Risk assessment workshops were then held with the utility managers, water engineers and operators to assess the risks and develop or review the DWMS. The study findings were used to inform the risk assessment. The workshops included analysis of case studies of global water quality incidences, in order to highlight the importance of water quality management, including communication protocols and record keeping. The development of the DWMS required a multidisciplinary team effort in order to ensure detailed analysis of water quality data, risk assessment, critical control point identification, improvement actions and documentation of the DWMS. The risk assessments involved wide representation and participation from multiple drinking water stakeholders. These included environmental health practitioners from the Public Health Unit (PHU), utility management and water operators and contracted water quality consultants (Table 3.2). The Hazard Analysis Critical Control Point approach was used for hazard identification and risk assessment.

Table 3.2 Drinking Water Management Systems (DWMS) stakeholders rural Hunter New England 2012

Organisation	Representation	Service
Water Supplier (Council)	Water Services Manager	Supplier services policy
	Water Services Engineer	Supplier services expertise
	Water Plant Operators	Supplier services plant operations
	Environmental Health Officer	Supplier services advice and regulatory requirements review and updates
	Asset Manager	Supplier services asset management and upgrades
NSW Health	NSW Health Water Unit	Provides expertise, advice and regulatory requirements review and updates
	Local Health District Environmental Health Office	Provides expertise, advice and regulatory requirements review and updates
NSW Health. Office of Water	Office of Water Inspector	Provides expertise, advice and regulatory requirements
Water Quality Consultant	NSW contracted Specialist	Independently facilitate the workshop
		Assist supplier develop the DWMS

The risk assessments included the following aspects of drinking water management:

- Discussing the study findings and assessing the sampling adequacy and guideline exceedance including *E. coli* detections;
- Determining general utility constraints in meeting the expected sampling adequacy;
- Analysing key water supply system characteristics including the catchments and supply flow diagrams;

- Identifying and document hazards, sources and hazardous events for each component of the water supply system;
- Estimating the level of risk for each identified hazard or hazardous event;
- Evaluating the major sources of uncertainty associated with each hazard and hazardous event and considering actions to reduce uncertainty;
- Identifying existing preventive measures from catchment to consumer for each significant hazard or hazardous event and estimating the residual risk;
- Evaluating alternative or additional preventive measures where improvement is required;
- Determining significant risks and document priorities for risk management;
- Determining the water characteristics to be monitored at the treatment plant and in the distribution system (operational monitoring) and in water as supplied to the consumer (verification monitoring);
- Documenting the critical control points, critical limits and target criteria;
- Establishing risk treatments (improvement actions) for all the unacceptable residual risks and any improvements to practices and procedures;
- Establishing and documenting a sampling plan for each characteristic, including the location and frequency of sampling;
- Establishing and documenting procedures for corrective action in response to non-conformance or consumer feedback;
- Establishing rapid communication systems to deal with unexpected events;
- Identifying training needs and establishing a staff training procedures and regularly testing of emergency response plans;
- Developing an active communication program to inform consumers and promote awareness of drinking water quality issues;
- Establishing a records management system and ensuring that staff are trained to fill out records;
- Developing and establishing an improvement plan; and
- Developing internal and external audit systems.

After the risk assessments the consultants supported the development of the DWMS with the participation of the stakeholders. The PHU environmental health officers reviewed drafts prepared by contractors and local water utilities. The PHU environmental health officers followed up on the implementation of the systems. The follow up observations were discussed with NSW Health Water Unit. A decision to assist and fund utilities with implementation was made. The priority was utilities that lacked technical or financial capacity. The consultants were re-engaged to assist the utilities to identify the required improvements and implementation strategies, after assessing areas of need. All stakeholder (Table 3.2) workshops were held to assist in the re-assessments. The operational and verification monitoring programs were reviewed and strengthened. Risk treatments (improvement actions) were assigned for all the unacceptable residual risks and any changes to the critical control points and improvements to practices and procedures were added to the respective DWMS as part of the improvement plans.

3.3 Results Summary

3.3.1 Joining the program

The water utilities and supply systems commenced sampling under the program to the program at different dates starting from January 2001 to April 2004 (Figure 3.2). Ninety-six percent (n = 63/66) of the utilities acceded to the program in 2001 and 4% (n = 3/66) acceded in 2004. The median joining date was 09 February 2001 with 23 January 2001 as the mode. The median number of years since the first water utility joined the program was 13.9 years with a mode of 14.95 years. The range was 3.25 years, and the standard deviation was 0.65 years.

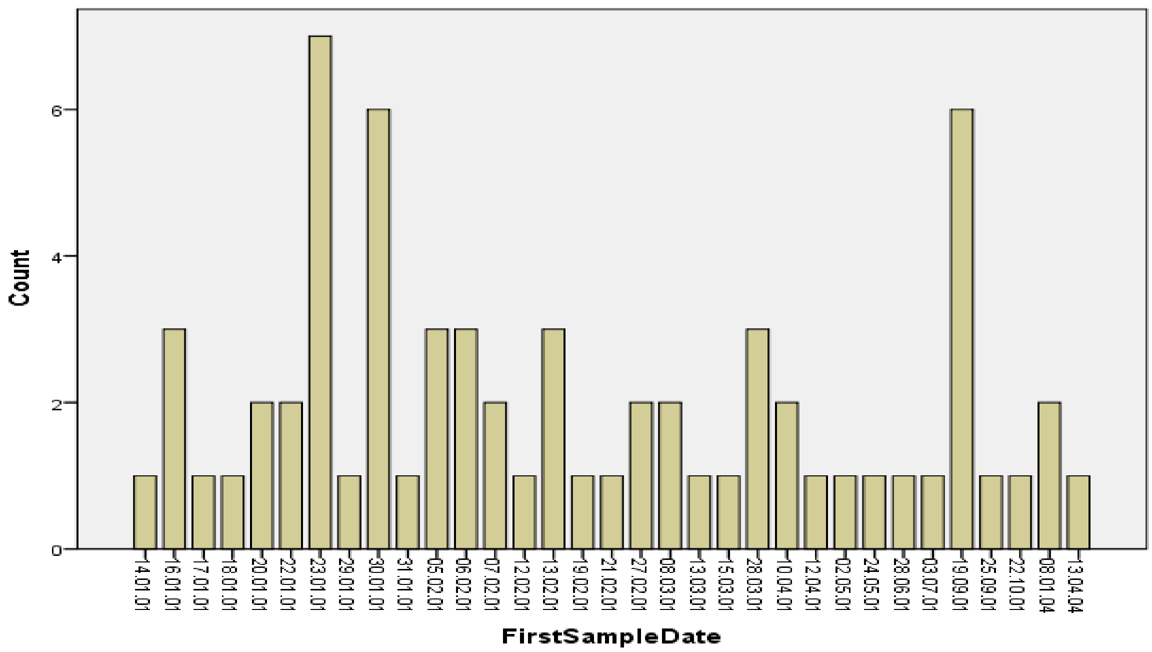


Figure 3.2 Dates and numbers when drinking water utilities joined the NSW Drinking Water Monitoring Program, regional Hunter New England, 2001-2004

3.3.2 Characteristics of the regional drinking water utilities and systems in HNE 2001-2015

Figure 3.3 represents the primary drinking water sources for each water supply system. The characteristics of the water systems in rural Hunter New England is presented in Appendix 1.

Figure 3.3 Primary drinking water sources in regional Hunter New England 2015 (Hunter New England Area Health Service, 2008)

3.3.3 Impact of water treatment

This section provides examples of the effectiveness of the improvements made to water treatment processes in small rural water supplies in the region. Particle removal and disinfection were the main improvements made to the various water treatment systems during the research period 2001-2015.

3.3.3.1 Particle removal

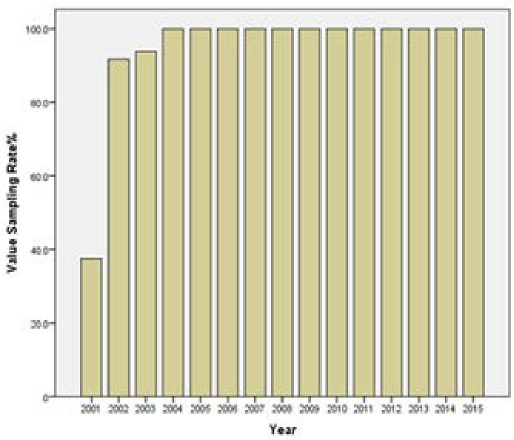
Particle removal is a water treatment process, which may include flocculation, coagulation, sedimentation and filtration (standard particle removal) to remove suspended matter. Ten out of the 19 watercourse sources used standard particle removal, and eight used sedimentation and filtration as the treatment methods, while one does not have a particle removal process at all. Five dam sources used clarification while three used sedimentation alone. Twenty-seven (79%) groundwater supplies have no particle removal treatment at all; three systems used the standard clarification method; two used pH correction; one had aeration and another one used silver ion. Three mixed sources (groundwater and watercourse) used the standard clarification method; one used sedimentation while two have no clarification. Approximately 65% of the population get clarified water. Clarification improved water quality whenever it was introduced (Box 1).

Box 1: Illustration of impact particle removal in drinking water

Town A

Town A, a town of 1,300 people, is served by river water. Disinfection was introduced at the inception of the water supply system without any clarification. The town commissioned powdered activated carbon and dissolved air floatation particle removal in 2011, and a drinking water management system in 2013. During 2001-2015, 701/719 expected samples were collected and tested. The sampling adequacy was increased incrementally until 2004 when it levelled off at full capacity (100%) (Figure 3.4). *E. coli* detections were frequent until 2011, although the detections became fewer. No *E. coli* exceedances were recorded after 2011, when the clarification was commissioned, coupled with the introduction of the mandatory drinking water quality management system in 2013 by the *NSW Public Health Act 2010* (NSW Government, 2010).

Sampling frequency rate



***E. coli* detection rate**

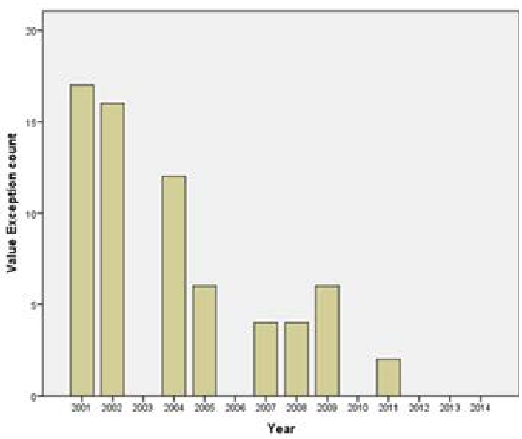


Figure 3.4 Drinking water microbiological sampling frequency and *E. coli* detections Town A 2001-2015 (River water 4 ML/day for 1300)

Town B

Town B, a town of 360 people, gets river water which was initially chlorinated without particle removal. Particle removal was introduced in 2005. The sampling adequacy has been satisfactory (Figure 3.5). There was a distinct reduction in sampling adequacy in 2004 due to administrative constraints during the mandatory local government amalgamations, at which time the system changed from one utility to another. *E. coli* detections drastically reduced after the introduction of clarification. No detections were made after the introduction of the mandatory drinking water quality management system by the Public Health Regulations 2012 (NSW Government, 2012).

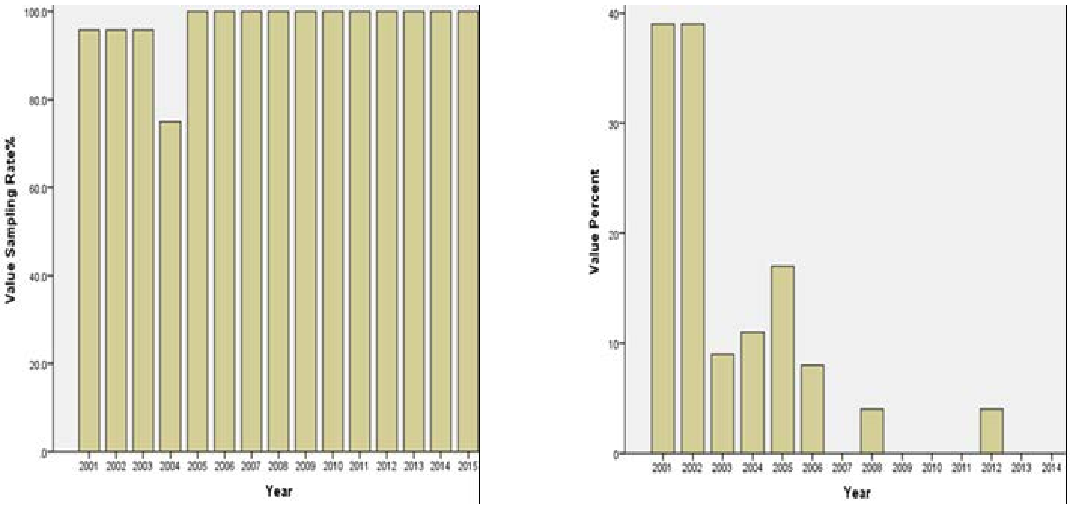


Figure 3.5 Drinking water microbiological sampling frequency and *E. coli* detections Town B 2001-2015 (River water 0.5 mL/day for 265 people)

3.3.3.2 Disinfection

All drinking water supply systems in the region are now disinfected. All except five ground water systems were chlorinated at the inception of the Drinking Water Monitoring Program. Chlorination was the primary disinfection method throughout the region (Table 3.3). Disinfection significantly improved the quality of the groundwater systems as illustrated in Box 2.

Table 3.3 Drinking water disinfection methods by primary water source and population served in regional Hunter New England, 2015

Disinfection method	Groundwater	Watercourse	Dam/lake	Mixed sources	No of supply systems	% supply systems	% population served
Chlorination only	31	16	6	5	58	89.4	88.8
Mixed	1	2	2	0	5	7.6	11.0
UV Light	1	0	0	0	1	1.5	0.1
Silver Ion	1	0	0	0	1	1.5	0.1
Total	**34**	**18**	**8**	**5**	**66**	100.0	100.0

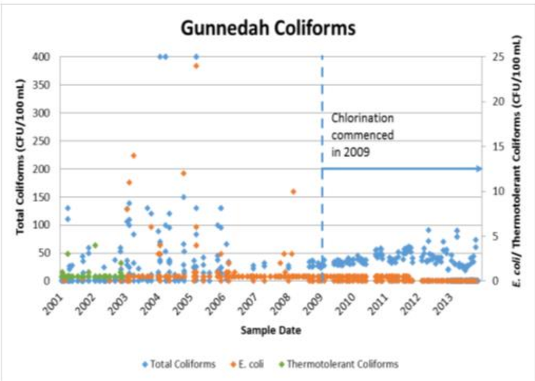
Box 2: Illustrations of the impact of disinfection on groundwater

A randomly selected water utility is used here to demonstrate the impact of disinfection on groundwater quality.

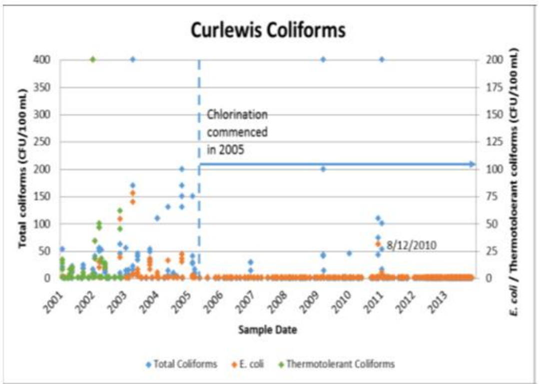
Gunnedah Shire Council

Gunnedah, a shire of 9,500 people, has groundwater and four supply systems. Curlewis system was disinfected in 2005. Mullaley and Tambar Springs were disinfected in 2007. Disinfection was commissioned in Gunnedah town in 2009. Currently, there is no particle removal at all four supplies in the shire. Generally particle removal is not needed for good quality bore water. The *E. coli* detections drastically decreased after the introduction of chlorination to each supply system respectively although detection of total coliforms remains an issue (Figure 3.6). The total coliforms may be due to biofilms in the old piping system.

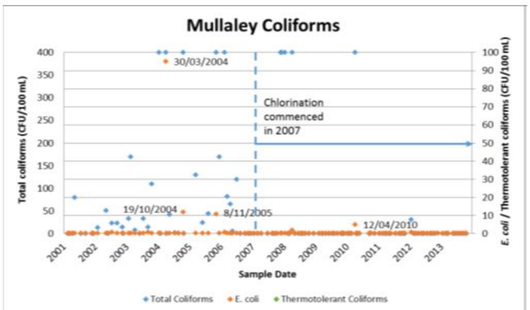
100% compliance after introduction of disinfection



>99% compliance after introduction of disinfection



>99% compliance after introduction of disinfection



>99% compliance after introduction of disinfection

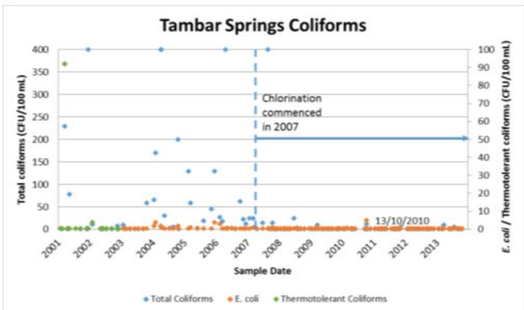


Figure 3.6 Drinking water microbiological sampling frequency and *E. coli* detections Gunnedah 2001-2015

3.3.4 Sampling adequacy

3.3.4.1 Annual sampling adequacy, all systems combined

The HNE region tested 40,744 out of 45,224 expected samples between 2001 and 2015. The sampling adequacy improved from 64% to 100% during the study period (Table 3.4).

Table 3.4 Annual sampling adequacy and *E. coli* detections, all systems combined, regional Hunter New England 2001-2015

Year	Expected Samples	Collected samples	Sampling Rate	*E. coli* Detections	*E. coli* Detection Rate
2001	2796	1809	64.7	90	5
2002	2802	2402	85.7	93	3.9
2003	2894	2395	82.8	59	2.5
2004	2926	2520	86.1	91	3.6
2005	2925	2291	78.3	68	3
2006	2922	2152	73.6	40	1.9
2007	2923	2760	99.4	43	1.6
2008	3003	2770	92.2	28	1
2009	2985	2908	97.4	28	1
2010	3037	2947	97.0	22	0.7
2011	3120	3060	98.1	16	0.5
2012	3187	3073	96.4	10	0.3
2013	3191	3143	98.5	15	0.5
2014	3247	3248	100.0	13	0.4
2015	3210	3266	100.0	2	0.1
Total	45224	40744	90.1	618	1.5

3.3.4.2 Annual sampling adequacy by water supply system

The 2001-2015 mean sample count per supply system was 617 samples (95% CI 435- 799). The median sample number was 413 samples with a standard deviation of 740 samples. The mean sampling rate per supply system was 89% (95% CI 84-91%). The median sampling adequacy was 95% with a standard deviation of 14.

Sampling adequacy statistically improved incrementally from 2001 to 2015 (p=0.0001 Wilcoxon Trend Test). There was a dip during 2005 and 2006, the period of mandatory local government amalgamations. The sampling standard deviation from the mean became incrementally smaller with time.

3.3.4.3 Annual sampling adequacy by Water Utility

The yearly utility sampling adequacy increased with time over the period 2001-2015 to reach 100% in 2015 (Table 3.4). Larger services had higher sampling rate than smaller utilities. The sampling adequacy significantly improved over the years (p=0.0001 Wilcoxon Trend Test). There were no distinct seasonal sampling variations except for summer due to the Christmas/New Year period when the laboratories close for up to two weeks annually, except for emergency samples.

Table 3.5 Annual sampling adequacy by utility regional Hunter New England, 2001-2015.

Local Government	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2001 - 2015**
Armidale	19	71	91	97	93	92	90	83	93	92	89	89	86	79	80	83.7
Glen Innes	57	58	44	47	50	74	44	53	44	50	47	67	96	92	100	61.1
Gunnedah	77	89	100	67	48	100	75	91	95	94	83	87	100	97	100	83.4
Guyra	63	78	82	83	100	100	90	100	100	100	97	100	100	100	100	96.9
Gwydir	36	80	81	100	99	42	100	100	100	100	100	100	100	99	100	95.7
Inverell	19	71	47	47	59	49	55	54	43	62	64	90	91	100	100	61.3
Liverpool	0	0	0	0	34	49	96	98	100	97	96	100	100	94	100	71.8
MidNorth Coast	100	100	100	100	60	45	100	100	100	100	100	95	97	93	100	100
Moree		100	100	100	73	83	85	97	98	98	100	90	100	100	100	98.2
Muswellbrook	69	99	100	100	100	100	100	100	100	100	100	100	95	97	100	89.3
Narrabri	38	100	87	99	100	99	100	100	88	98	100	100	100	98	100	99.1

Local Government	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2001 - 2015
Sealrocks	0	38	100	33	33	46	42	42	77	100	100	25	50	0	0	100
Singleton	100	73	97	100	98	60	100	39	100	74	99	100	97	88	97	96.2
Tamworth	67	97	93	87	93	93	98	100	100	100	100	100	100	92	100	68.9
Tenterfield	0	0	0	81	79	94	85	53	100	100	100	81	78	51	86	96.8
Upper Hunter	79	100	100	94	98	90	93	81	93	97	96	99	95	97	98	96.1
Uralla	61	68	64	57	63	100	100	100	100	97	92	99	100	95	99	67.7
Walcha	42	37	57	60	72	80	78	90	95	100	100	100	100	86	87	95.2
Total	64	85	85	85	75	73	94	94	97	96	97	96	98	93	100	90.6
Mean	53	75	80	76	76	76	85	82	90	87	86	90	93	91	96	79.8

Legend
Orange = <90% non-compliant
Yellow = 90 - <98% compliant
Green = 98 - 100 % fully compliant
No fill = Not part of program

3.3.4.4 Monthly sampling adequacy by system

The sampling adequacy showed some seasonal trends (Figure 3.7). The monthly sampling adequacy was lowest in December and highest in March for most systems (Appendix 3). The lowest sampling adequacy can be explained by the effects of the festive season when the laboratories close down, and most sampling officers, especially for smaller systems, are on holidays. April also showed lower sampling than other months due to the effect of Easter holidays. March had high sampling rate because of the compensatory sampling for the festive season and follow up by the Public Health Unit (PHU).

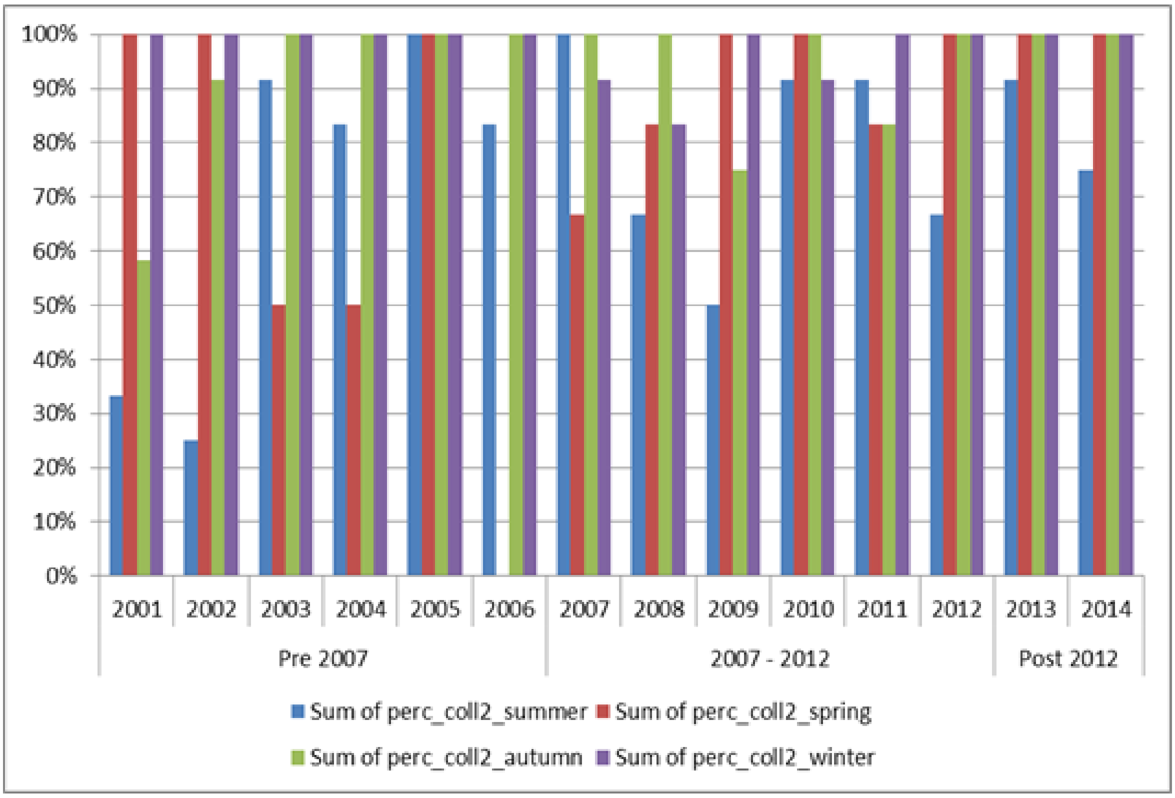


Figure 3.7 Sampling adequacy by seasons, regional Hunter New England, 2001-2014

Although 100% is the ideal sampling adequacy by the program protocol, circumstances such as staff turnover, work load, weather conditions and lost samples during sample transportation and testing processes may make it difficult to achieve. Hunter New England PHU, generally considers 90% adequacy as acceptable compliance. Nine out of 66 (14%) of the water supply systems had 100 % compliance. Eighty percent (n= 53/ 66) of the supply systems had a sampling adequacy of more than 95%, and 61/66 (92%) of the supply systems had more than 90% sampling adequacy.

3.3.5 *E. coli* detections

In the 15 years under review, only three systems served with clarified river water fully complied with the ADWG and and NSW Health target throughout the study period (at least 98% of samples contained no *E. coli*) (Appendix 4). The target existed in the ADWG in the early years of the program, but was removed in the ADWG 2011. However, NSW Health has retained the 98% target in our programs. Five other systems had no *E. coli* detections, but the sampling adequacy was less than 98%. Four of these received non-clarified bore water. One had clarified dam water. Overall, 33 (50%) supply systems had less than 1% *E. coli* detection rates. The mean *E. coli* detection rate was highest in bores in all community groups. The mean *E. coli* detection rate was similar for rivers and dams.

3.3.5.1 E. coli detections by water utility

During the period 2001-2015, eight out of the 18 (44.4%) water suppliers had less than 1% overall *E. coli* detection rate (Table 3.5). Six more utilities (33.3%) had less than 2% *E. coli* detection rate and four had more than 2% detection rate. The *E. coli* detection rate significantly decreased with time. *E. coli* detections were higher during warmer months than cooler months (Table 3.6). The detections improved with time (Table 3.7).

Table 3.6 Monthly *E. coli* detection by water supply utilities, regional Hunter New England, 2001-2015

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total detections	Samples collected	%
Armidale	2	1	0	0	0	0	0	0	0	0	2	1	6	1261	0.5
Glen Innes	2	1	6	5	7	4	4	1	1	4	3	1	39	660	5.9
Gunnedah	15	7	12	7	4	1	3	0	3	9	7	6	74	1652	4.5
Guyra	3	2	2	2	0	1	1	1	1	1	0	1	15	966	1.6
Gwydir	9	13	10	9	10	3	4	3	11	4	3	7	86	1893	4.5
Inverell	1	3	0	0	0	0	0	1	0	0	0	1	6	1275	0.5
Liverpool	8	8	7	6	2	4	0	0	2	2	6	7	52	2721	1.9
Midcoast	19	19	12	11	11	8	2	3	8	12	27	12	144	9723	1.5
Moree	5	5	5	5	5	0	4	1	2	3	10	4	49	2574	1.9
Muswellbrook	0	1	2	1	0	1	0	1	0	2	0	0	8	2010	0.4
Narrabri	4	4	0	1	0	3	1	1	2	3	5	1	25	3117	0.8
Seal Rocks	0	0	0	0	0	0	0	0	0	0	1	1	2	146	1.4
Singleton	0	2	0	0	0	0	0	1	0	0	0	0	3	1597	0.2
Tamworth	15	8	5	4	3	4	2	4	2	2	9	8	66	5191	1.3
Tenterfield	1	0	0	0	0	1	0	0	0	0	1	0	3	731	0.4
Upper Hunter	0	1	3	2	4	0	1	0	2	1	1	1	16	3519	0.5
Uralla	3	2	2	1	2	0	1	0	1	1	3	5	21	979	2.1
Walcha	0	2	0	0	0	1	0	0	0	0	0	0	3	729	0.4
Total	87	79	66	54	48	31	23	17	35	44	78	56	618	40744	1.5

Table 3.7 Annual *E. coli* detection frequency by month (overall) all systems regional Hunter New England, 2001-2015

Month	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	Total
Jan	10	15	4	17	7	5	4	0	4	6	3	3	5	3	1	87
Feb	10	14	9	10	5	9	6	3	2	0	5	2	1	2	1	79
Mar	11	9	3	8	9	4	8	5	4	0	3	0	0	2	0	66
Apr	10	5	8	7	8	3	4	5	1	2	0	0	0	1	0	54
May	8	8	3	4	6	0	4	7	1	3	1	1	0	2	0	48
Jun	8	2	3	6	5	1	1	1	2	1	0	0	0	1	0	31
Jul	3	5	1	4	2	0	1	2	2	2	0	0	1	0	0	23
Aug	0	4	2	2	2	1	1	0	1	1	1	1	1	0	0	17
Sept	5	12	6	6	2	1	2	0	1	0	0	0	0	0	0	35
Oct	4	4	5	12	2	3	6	2	2	1	1	0	2	0	0	44
Nov	11	9	9	9	11	7	4	2	6	4	2	1	2	1	0	78
Dec	10	6	6	6	9	6	2	1	2	2	0	2	3	1	0	56
Total	90	93	59	91	68	40	43	28	28	22	16	10	15	13	2	618

3.3.6 Gaps in drinking water management systems

The meetings and workshops found that only the two large rural utilities of Tamworth and Manning District (service population 25,000-99,999) had developed drinking water management systems by the *NSW Public Health Act 2010* (NSW Government, 2010). However, the systems had not been fully implemented. The smaller utilities reported lack of adequate financial and human resources to develop the management systems. Long distances travelled for water sampling purposes were frequently cited as the main causes of low sampling rates. Reservoir integrity was also reported to be the main cause of *E. coli* detections.

The other main gaps identified included:

- Some water utilities' strategic business plans did not include drinking water stakeholder communication protocol;
- Utilities did not regularly review drinking water quality data;
- Utilities did not have documented standard operational procedures and critical control points (CCP) for the water quality management. Procedures to capture all operation, inspection, maintenance and monitoring related activities from catchment to consumer were not established and documented;
- Utilities had no documented disinfectant contact times (C.t) for the various water supply systems. The C.t concept describes the relative effectiveness of a specific disinfectant against different microorganisms under specified conditions of concentration of the disinfectant, turbidity, temperature and pH. Generally, in clean water, a residual chlorine level of 0.5 mg/L after a contact time of 30 minutes should be sufficient to ensure microbial control, given a clean distribution system and no significant recontamination (NHMRC, 2011). This suggests that a minimum C.t of 15 mg.min/L is required;
- Utilities had no Safe Work Method Statements (SWMS) for receipt and handling of chemicals from suppliers;
- Utilities had no Incident and Emergency Response Protocols for drinking water contamination incidents by the NSW Health's response protocols. There was an urgent need for staff training and developing emergency response plans;
- Utilities had no documentation processes for investigating incidents or evaluating emergency response plans in that incident and implementing necessary improvements;
- Utilities had not developed validation processes for the performance of new or upgraded processes;

- Smaller systems had no online operational monitoring systems. Such systems depended on physical inspections to validate functionality;
- Finished water and distribution reservoirs were not routinely inspected; and
- Utilities often complained that they were not getting any feedback or incentives from the public health unit for sampling activities despite the existence of the data in NSW Drinking Water Database.

All water utilities in the Hunter New England region were recommended to and did receive assistance from NSW Health to develop the drinking water management systems. NSW Health contracted skilled water quality and engineering specialists to assist the utilities to close the gaps identified during the workshops (Byleveld et al., 2016). The two large (R1) utilities had developed the DWMP and were assisted in the implementation, audits, identification of CCP and development of improvement plans. Ten utilities got additional support to initiate the implementation processes, review critical control points, establish standard operational procedures develop improvement plans and train operators.

Discussion

The introduction of the *NSW Public Health Act 2010* (NSW Government, 2010) and NSW Public Health Regulations 2012 (NSW Government, 2012) mandating the requirements for the drinking water quality assurance programs (drinking water management systems) in 2014 coincided with this research project. Quality assurance programs are important tools in ensuring the safety of drinking water because they describe the water supply, identify risks, and detail the actions to be taken to protect the quality of water provided to consumers. At the heart of the Australian Drinking Water Guidelines Framework are critical control points (CCPs) (NHMRC, 2011). A critical control point is defined as an activity, procedure or process at which control can be applied and which is essential to prevent a hazard or reduce it to an acceptable level (NHMRC, 2011). CCPs must be monitored regularly, ideally continuously, to ensure the effectiveness of barriers. Properly operated CCPs help ensure safe drinking water (NSW Health 2018a). Department of Industry (DoI) Water and NSW Health have recently endorsed a new fact sheet on critical control points for drinking water management systems, the most important CCPs are filtration (where present), disinfection and maintaining reservoir integrity (NSW Health, 2018a). Water utilities may establish other CCPs, including fluoridation and selective abstraction of raw water. The ADWG CCP values have been adopted throughout the region as recommended by NSW Health (Table 3.8).

Table 3.8 Hazards and Critical Control Points for effective drinking water quality management (NHMRC, 2011).

Hazard	Control	Monitoring characteristic, location	Critical limit
Chlorine sensitive pathogens	Chlorination	Chlorine concentration after contact time (e.g. at outlet of clear water tank)	Minimum free chlorine concentration for C.*t* (concentration and contact time) of 15 mg.min/L
Naegleria fowleri	Chlorination	Chlorine concentration after contact time (e.g. at outlet of clear water tank)	Minimum free chlorine concentration for C. *t* (concentration and contact time) of 30 mg.min/L
Chlorine sensitive pathogens	Chlorination	Turbidity at point of chlorination	Turbidity less than 1 NTU
Chlorine resistant pathogens	Filtration	Turbidity at individual filter outlet	Maximum turbidity 0.5 NTU
Pathogens from vermin	Integrity of reservoirs	Regular inspection of reservoirs	Evidence of contamination

Since 2014, utilities and NSW Health Water Unit, HNE Public Health Unit, utilities and the specialists have held DWMS implementation workshops and reviews highlighting the fact that the sampling adequacy and detection of *E. coli* are key parts of management systems. The reviews considered critical control point performance, response to exceptions, and progress on actions and improvements. A complete review is conducted every four years in line with Strategic Business Planning. The reasons behind the sampling adequacy and water quality *(E. coli* detections) shortfalls and possible solutions were discussed and included in the management systems improvement plans.

Consultants conducted operator on-the-job training to ensure that operators understood the procedures, documented management activities, and followed record keeping and reporting requirements in accordance with the DWMS. Corporate commitment to conduct and participate in research and development activities on drinking water quality issues is essential (Cosgrove and Rijsberman, 2000; Grayman et al., 2012; NSW Health, 2013). Such commitment helps to ensure continual improvement and the ongoing capacity to meet drinking water quality requirements (NHMRC, 2011; WHO, 2017). Natural and human systems have an ability to adapt to change to a certain extent with the existing knowledge and technology (Cosgrove and Loucks, 2015). Research is needed to better understand the cultural dimensions impacting upon water management practices and how they affect human behaviour in different societies (Cosgrove and Loucks, 2015).

The participation of water operators in workshops made it easier to pin-point problems they were facing which were yet to be addressed. Such problems included long distances travelled to sampling sites resulting in shortcutting sampling procedures to save time and the need for training replacement staff in case the incumbent sampling officer is away on short notice. These issues could result in fewer samples being taken and accidental contamination of the samples resulting in *E. coli* detections. The knowledge, skills, leadership, staff retention motivation and commitment of staff are key drivers of a utility's ability to operate a water supply system successfully (Peletz et al., 2018). It is vital that awareness, understanding and commitment to the DWMS, including performance optimisation and continuous improvement, are developed and maintained within the organisation (NHMRC, 2011). Employees need to have appropriate skills and training in all aspects of their job in order to operate the water supply system. An understanding of drinking water quality management is essential for empowering and motivating employees to make effective decisions. All employees involved in drinking water supply must be aware of:

- The organisation's drinking water quality policy;
- Characteristics of the water supply system and preventive strategies in place throughout the system;
- Regulatory and legislative requirements;
- Roles and responsibilities of employees and departments; and
- How their actions can impact on water quality and public health (NHMRC, 2011, O'Connor, 2002).

The development of standard operating procedures displayed at working sites as part of the management systems mitigated against such practices. This annual internal review should consider critical control point performance, response to exceptions, and progress on actions and improvements. A complete review should be conducted every four years in line with strategic business planning.

During the workshops, it was observed that some small utilities, including those serving discrete Aboriginal communities, lacked the financial and technical capacity to sustain the systematic processes for operation and maintenance of the infrastructure and services required to adequately meet the requirements of the Drinking Water Monitoring Program and the *NSW Public Health Act 2010* requirement for drinking water management plans. Small water supplies were below target for sampling frequency and water quality. Detection of *E.*

coli was significantly more common. A previous study found that almost 40% of systems did not meet the target (i.e. no more than 2% of samples positive) for *E. coli* state-wide (Cretikos et al., 2010). Before the program began in 2008, local Aboriginal land councils were responsible for water and sewerage infrastructure on their land. Most had small populations, and lacked the financial and technical capacity to sustain services (Byleveld et al., 2016). NSW Health recognised the importance of supporting regional utilities, especially those with limited engineering expertise and financial capacity.

During the development of drinking water management systems, control measures for the identified risks were determined, discussed and agreed upon. The multi-barrier approach, local setting, available resources and technology were deliberated upon. The multi-barrier approach encourages catchment management; water source protection; removal of particles from the water; killing or inactivating pathogens; effective distribution and prevention of re-contamination of treated water (Mudaliar et al., 2012; NHMRC, 2011). Effective catchment management decreases contamination of source water. The amount of treatment chemicals and quantity of the chemicals needed can be reduced, and hence the cost. Public health benefits through optimising disinfection, reduced production of disinfection by-products, and economic benefits through minimizing operational costs are realised (NHMRC, 2011). Catchment protection is recommended as the first line of defence for drinking water schemes (NHMRC, 2011). Preventive measures should be applied as close to the source as possible, focusing on catchments rather than reliance on downstream control (WHO, 2011a). Water distribution systems should be fully enclosed and storages should be securely roofed with external drainage to prevent contamination (WHO, 2011a).

Case studies of examples of how failure to adhere to the management system provisions that have led to drinking water diseases outbreaks/incidences e.g. Milwaukee, USA; Walkerton, Canada; Őstersund, Sweden; and Northampton, England (Hrudey and Hrudey, 2014) were always highlighted. Utilities are now reporting failure to take the required number of samples, *E. coli* detections, the reasons behind and actions taken to improve as part of the annual review of the drinking water management systems submitted to the PHU. Improvement plans are part of the review system. The engagement of the utilities in realizing the importance of drinking water monitoring as part of the management plan has heightened the sampling adequacy to 100% per annum in all the utilities. Where the target is not met in a particular period due to unforeseen circumstances, compensatory samples are taken in the proceeding period. Vigilance on operational and distribution system integrity have improved due to strict adherence to the management system requirements.

The PHU follow-ups with utilities with high *E. coli* detections to confirm the water supplier is adequately controlling the risk by adhering to critical control points helped to lower the incidences. Improvement actions were prioritised by having regard to the actual or potential risk to public health and the utilities' resourcing and competing work priorities. All utilities had developed drinking water management systems by 2015. Implementation of the management systems is an ongoing process involving improvement plans and annual reviews jointly undertaken with the PHU. Engagement with specialist contractors and utilities to review management systems, CCP performance, risk assessment findings, and actions and improvements is continuing (Byleveld et al., 2016). Emphasis is focused on online monitoring of filtration (measured as water turbidity), disinfection measured as chlorine residual, and visual inspection of reservoirs (reservoir integrity) as the operational CCPs targets and limits. Complying with the CCPs, routine sampling frequency targets and non-detection of *E. coli* are the verification procedures employed by the PHU.

Utilities report exceptions to the CCPs, noncompliant test results and missed samples to the PHU with investigations carried out, actions taken and procedures to avoid repeat incidences. NSW Health has developed a spread sheet template to record all reported exceedances which subsequently forwarded to NSW Health for collation with the rest of the state. The reports will be used to improve drinking water management at state level. The response to exceeding a CCP limit, service reservoir contamination and *E. coli* detection has been linked to the NSW Health Response Protocol for Managing Pathogen Risks in drinking water (NSW Health, 2011). A de-brief after an incident is required so that improvements can be identified.

3.5 Research impact

This study help to provide evidence-based impetus for the development and implementation of drinking water quality management systems (DWMS) in small regional water systems (now mandatory in NSW since 2014). DWMS present a risk-based, proactive framework for drinking water quality management, and when properly implemented, virtually eliminate the option for complacency (Kot et al., 2015).The highlighting of shortfalls in the sampling adequacy and *E. coli* detections coupled with the gaps identified during the stakeholder workshops, especially for small utilities in the region, has helped justify continued NSW Health funding and assistance for water utilities to develop and implement the drinking water management systems. Emphasis was placed in the identification and management of CCPs for water treatment (filtration measured as turbidity, and disinfection measured as residual chlorine) and water distribution systems (reservoir integrity).

Utilities in the region were also assisted in identifying operational control points for raw water reservoirs, intake systems, treatment optimisation and standard operating procedures (SOP). CCPs and SOPs promote a proactive approach to managing drinking water quality.

CCPs and SOPs formalise the processes and activities undertaken by water utility staff, and ensure that responses are carried out consistently, effectively and efficiently. Deviation from critical limits and SOP indicates loss of control of the process or activity and regarded as posing a potential health risk.

Drinking water supply performance reviews, water treatment improvements, corrective maintenance actions and regulatory changes have been implemented to improve the safety of drinking water. These measures have resulted in improved sampling adequacy and microbiological quality in Hunter New England region and the state of NSW. Based on the advice from NSW Health, the use of continuous online instrumentation for measuring water quality parameters such as turbidity and chlorine residual has been adopted, or will soon be adopted, by water utilities. Continuous monitoring of critical control points allows more consistent control of water quality.

The implementation of the DWMS gives confidence in water quality. Records of *E. coli* monitoring in conjunction with sanitary inspections, turbidity and residual disinfection levels now form the basis of water quality verification statewide. The study findings on sampling adequacy and *E. coli* detections were highlighted during the workshops and were used in the risk assessments during the development of water quality management systems of the respective utilities. It was commonly noted that the detection of *E. coli* was a delayed process, sampling adequacy was not always satisfactory and some supply systems were remote. Online monitoring of filtration and disinfection processes were recommended as the best way to verify water quality. The participation of NSW Health in the study and workshops, coupled with other programs supported the timely adoption of recommendations. NSW Health has assisted in funding specialist contractors to help with drinking water management system implementation. This has included supporting improvements to operational monitoring and recording, which has now been implemented in most rural water supplies. Real-time monitoring remains an important goal in ensuring the consistent quality of the water supply although episodic and routine contamination events are difficult to predict and identify (Mack and Choffnes, 2009; Reynolds et al., 2008).

In Hunter New England, improved drinking water operational monitoring enhances transmission of critical control point data in real time, provide a better understanding of the water supply systems and allows for timely operational responses. The supervisory control and data acquisition (SCADA) software enables water managers to respond more rapidly to incidences and has provided an opportunity to review sampling adequacy and improve water safety. The electronic data enables operators of water supplies to perceive short-term and long-term trends in water quality, such as water treatment plant performance during different raw water quality conditions. All utilities had developed and implemented drinking water management systems by the end of the study period in 2016. Utilities were still being assisted in the implementation of the improvement plans, with assistance from NSW Health-contracted consultants, especially in the identification of CCPs and their respective management strategies.

The current research and workshops has helped justify the continued support to water utilities in the implementation of comprehensive drinking water management systems to improve drinking water safety in accordance with the *NSW Public Health Act* 2010 requirements, thereby enhancing relationships between NSW Health and water utilities. The NSW Drinking Water Database has been improved to incorporate the deficiencies identified during the data processing stage of the study, thereby improving the efficiency of the NSW Health Drinking Water Monitoring Program.

A review to determine the impact of the management systems and the real-time electronic monitoring has not been carried out. A review of the sampling adequacy and *E. coli* detections showed that the sampling adequacy and *E. coli* detections had improved to almost 100% (Jaravani et al., In review[a]). Water suppliers, NSW Health PHUs and contractors have reported many benefits after the risk assessment workshops. The benefits include having one central source of information to manage all components of a water supply, increased staff awareness of the processes critical to the supply of water, and the identification of areas requiring improvement (Byleveld et al., 2016). The positive outcomes of the risk assessment workshops and specialist contractor assistance include:

- Defining critical control points for each supply system;
- Confirming effectiveness of chlorine disinfection of drinking water;
- Documenting standard operating procedures;
- Improvement to record keeping;
- Identification of water treatment plant design risks;
- Online monitoring of water quality data;
- Optimisation of water treatment plant processes;
- Support for replacement or upgrades of aged infrastructure or new infrastructure; and
- Improved communication.

The application of this research evidence and other programs has highlighted the value of NSW Health working more closely with local councils, government agencies and industry associations in order to promote awareness of the quality assurance program requirements for private water supplies and water carters. NSW Health has published updated NSW Private Water Supply Guidelines and NSW Guidelines for Water Carters, water treatment fact sheets, and sample quality assurance program templates that can easily be adapted for different water supplies. NSW Health's Local PHUs has worked with contractors to develop quality assurance programs for different types of private water supplies, including bore, river water and rainwater systems.

3.4. 2 Journal publication

The discussion on univariate and multivariate analyses of the results are inserted as a copy of the journal article:

Jaravani, F. G., Butler, M., Byleveld, P., Durrheim, D. M., Massey, P. D., Judd, J. & Oelgemöller, M. Drinking water quality in regional Hunter New England, New South Wales, Australia, 2001-2015. *Journal of Water and Health (Under review, JWH-D-18-00051).*

Drinking water quality in regional Hunter New England, New South Wales, Australia, 2001-2015

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Abstract

This study evaluated the completeness of drinking water microbiological quality monitoring in regional New South Wales, Australia. Sampling adequacy and *E. coli* detection data were obtained from the NSW Drinking Water Database. Statistical analysis was performed using Incidence Rate Ratios to determine sampling adequacy, *E. coli* detection and the relationship between sampling adequacy and *E. coli* detections over time.

Sampling adequacy and *E. coli* detections significantly improved during the study period. Sampling adequacy was significantly lower in smaller populations (IRR = 0.83, p = 0.036). *E. coli* detections were significantly increased in smaller communities (IRR = 4.3, p =0.01) and in summer (IRR=2.7, p=< 0.001). There was a strong inverse correlation between improved sampling adequacy and decreased *E. coli* detections (Spearman's rho =-0.821; p<0.0001).

This research has highlighted the value of continued assistance to water utilities in the implementation of drinking water management systems to improve drinking water safety.

Keywords

Drinking water quality; drinking water monitoring; sampling adequacy

Introduction

Drinking water that is microbiologically compromised can have a detrimental effect on public health. Pathogenic microorganisms are a primary cause of waterborne disease globally (Sobey 2006). The national *Australian Drinking Water Guidelines 2011* (Australian Guidelines) provide guidance on ensuring the safety of drinking water and include a risk-based *'Framework for management of drinking water quality' (The Framework*) (NHMRC 2011). The Framework moves away from reliance on endpoint testing and encourages the early identification and control of problems, thereby reducing the likelihood of contamination.

In Australia, 54 of 6,515 (0.83%) gastroenteritis disease outbreaks were classified as either 'waterborne' or 'suspected waterborne' between 2001 and 2007, of which 10 (19%) were associated with drinking water (Dale et al. 2010). The implicated pathogens were found on all but one occasion and included *Salmonella sp.* (five outbreaks), *Campylobacter jejuni* (three outbreaks) and *Giardia* (one outbreak) (Dale et al. 2010). The outbreaks were mainly due to contaminated tank and bore water, not reticulated public water supplies. This likely represents an underestimation of water-associated events due to difficulties in identifying, categorising and obtaining microbiological and epidemiological evidence of gastroenteritis outbreaks (Dale et al. 2010).

In New South Wales (NSW), water utilities are responsible for the safety of the drinking water they supply to consumers. NSW Health is the public health regulator of drinking water (Byleveld et al. 2016). NSW Health has provided drinking water testing for local water utilities across the state for more than a century.

The present study focused on drinking water supply system performance, reflected by microbiological sampling adequacy (proportion of samples collected to the allocated number) and microbiological quality (*E. coli* detection) of drinking water supplied to regional communities in the Hunter New England Local Health District (HNELHD) between 2001 and 2015. Compliance monitoring provides verification that preventive measures are effective, rather than as the primary means of protecting public health (Sinclair and Rizak 2004). The objective of this study was to evaluate the effectiveness of verification monitoring as a means of improving preventive measures and provide an insight into the impact of progressive legislative and administrative changes on drinking water quality in the Hunter New England area of NSW.

Institutional and regulatory review

An Independent Inquiry into Secure and Sustainable Urban Water Supply and Sewerage Services for Non-Metropolitan NSW (Inquiry) was conducted by the NSW Government in 2007-2008 (Armstrong and Gellartly 2009). NSW Health shared with the Inquiry Panel analysis of drinking water quality in regional NSW from 2001 to 2007, including the finding that water supply systems with inadequate disinfection or serving small populations were more vulnerable to faecal contamination (Cretikos et al. 2010). The Inquiry highlighted the need to improve management of drinking water quality. Amendment of the NSW *Public Health Act* in 2010 (NSW Government 2010) provided an opportunity to establish the requirement for drinking water risk management in legislation.

The NSW *Public Health Act 2010* (NSW Government 2010) requires all drinking water suppliers (including local water utilities) to implement a quality assurance program that addresses the Australian Guidelines' Framework for Management of Drinking Water Quality. NSW Health refers to the quality assurance program for a water utility as a 'drinking water management system' to emphasise the importance of implementing a system rather than simply preparing a plan. A drinking water management system consists of documents, procedures and other supporting information for the safe supply of drinking water. As part of the development of their drinking water management system, each water utility was required to review how they complied with the requirements of the Program, including the regular review and follow-up of results (NSW Health 2013). NSW Health works closely with utilities and industry to promote awareness of the requirements and share information and offers all local water utilities support for the development and implementation of their management systems.

Analysing drinking water quality trends allows water utilities to better manage drinking water quality and enables health authorities to improve policy and response.

NSW Health Drinking Water Monitoring Program

In regional NSW, drinking water microbiological compliance is verified through the NSW Health Drinking Water Monitoring Program (Byleveld et al. 2008; NSW Health 2005). The current Program has been operating since 2001 and offers free testing, guidance on sampling, and protocols to guide action when contamination is detected (NSW Health 2013). The Program has provided a mechanism for NSW Health to exercise public health oversight of water utilities in regional NSW (Byleveld et al. 2016). Since 2001, local water utilities (generally local councils), NSW Health and NSW Department of Industry Water have participated in the Program (NSW Health 2005). By the end of 2004, all drinking water supply systems were participating in the Program.

At the heart of safe drinking water is the operation of critical control points (CCPs), those components of supply systems that control health risks (e.g. post filter turbidity, chlorine). The Program emphasises prompt follow up of non-compliance, resampling, investigation of the possible causes of contamination, improved treatment, establishment and adherence to CCPs, maintenance of free residual chlorine, low water turbidity and prompt reporting of CCP exceedances.

The verification measure for microbial water quality is that no *E. coli* bacteria should be detected in a minimum 100 mL sample of drinking water. A water utility is considered compliant for microbiological water quality when the expected number of samples (sampling adequacy) have been tested, and at least 98% of samples have no *E. coli* detected in a minimum 100 mL sample of drinking water. The annual number of samples allocated is based on the population served and the complexity of the system by the Australian Drinking Water Guidelines (NSW Health 2005). Samples for monitoring water safety are collected from locations in the water supply system that are representative of the supply to consumers, such as taps in public locations and private residences. The drinking water samples are analysed by NSW Health laboratories accredited by the National Association of Testing Authorities (NATA).

Every year, NSW Health allocates water utilities a recommended number of tests labels for drinking water quality monitoring samples, based on the population that their system supplies. Allocated samples are tested for free through NSW Health laboratories. The microbiological test results for each water supply system are reviewed and monitored by the local public health unit (PHU) within which the water utility is located.

Laboratories enter drinking water quality monitoring test results into the NSW Drinking Water Database (Database), a password protected web interface. The Database stores drinking water quality monitoring results and provides secure access for NSW Health and local water utilities (Byleveld et al. 2008).

The role of Public Health Units (PHUs) within each NSW Local Health District (LHD) is to monitor sampling compliance and treatment requirements for water utilities within their jurisdiction. PHUs review the Database to check sampling compliance and are notified by laboratories of any *E. coli* detections. PHUs monitor utility adherence to CCPs, especially chlorine residual, turbidity, treatment regime and reservoir integrity (NSW Health. Office of Water 2014). PHUs may assist in sanitary investigations where necessary. If a risk to public health is identified, PHUs will advise the water utility to issue a 'boil water' alert or other appropriate warnings to the community (Byleveld et al. 2008). The NSW Department of Industry Water provides technical support to utilities through a network of regional officers, the Best-Practice Management of Water Supply and Sewerage Guidelines and by training water treatment plant operators (Samra and McLean 2007).

Study setting

The Hunter New England (HNE) region is situated to the north east of Australia's most populous state, New South Wales. The region covers an area of 131,785 square kilometers and has a population of over 873,741 residents. Aboriginal people make up four per cent of the population. The majority of regional HNE communities (approximately 250,000 people) rely on drinking water supplies managed by local water utilities (generally local governments). Metropolitan Newcastle is served by Hunter Water Corporation under different regulatory provisions and was therefore excluded from this study. The population data used in the study is based on service connections to water systems recorded in the NSW Drinking Water Database rather than census data; census data includes peri-urban and rural properties with their own private water supplies, which are not covered under this regulatory system.

Methods

Data on drinking water sampling compliance and *E. coli* detections for rural drinking water supply systems in the HNE region from 2001-2015 were obtained from the NSW Drinking Water Database. Six water supply systems were excluded because they are declared non-potable supplies.

W*ater source and treatment*

Information on water sources and treatment methods were obtained from each water utility. *E. coli* detections were aggregated by water source type and analysed as a group. The effect of significant changes (e.g. particle removal and disinfection) to water treatment regimes were analysed by comparing *E. coli* detection rates before and after the introduction of the changes and calculating Incident Rate Ratios (IRR) using Stata version 14.2 (STATACORP LLC 2016).

Sampling adequacy

Sampling adequacy was defined as the proportion of samples collected out of the expected (allocated) number of samples. Sampling adequacy was examined by the size of the population served, the type of water source, the use of water treatment and year. Odds ratios and p-values were calculated using IRR. The change in sampling adequacy over the years was examined using the Wilcoxon test for Trend.

E. coli detections

E. coli detections were analysed by calculating the proportion of microbiological samples with *E. coli* detections out of the total number sampled. Multiple detections of *E. coli* recorded for samples collected on the same date from the same sampling site in a distribution system were treated as a single contamination event. Multiple *E. coli* detections on the same date, from different sampling sites in the same distribution system, were also treated as a single contamination event unless each was an allocated sample from NSW Health. The assumption was that a single contamination event would affect the whole distribution system, although multiple contamination events may be possible.

E. coli detections were examined by the size of the population served, the type of water source, the use of water treatment and year. Univariate and multivariate Incident Rate Ratios and 95% confidence intervals were calculated using IRR.

Correlation between sampling compliance and E. coli detections

The correlation between sampling compliance and *E. coli* detections was examined by calculating Spearman's Rank Correlation Coefficient.

Administrative and legislative changes

The impact of administrative and legislative changes on sampling compliance and *E. coli* detections was examined over time

Ethics

Ethics approval for the project was granted by the Hunter New England Human Research Ethics Committee (HNEHREC 13/10/16/5.06); NSW Human Research Ethics Committee (NSWHREC LNR/13/HNE/418) and James Cook University Ethics Committee (H5085).

Results

Population served

The regional Hunter New England area has 66 public drinking water supplies serving approximately 250,050 people (2015) based on service connections. Sixty-four water supplies are operated by local government councils. The remaining two include the largest water utility, which is structured like a county council serving three local government areas (approximately 62,400 people); and a holiday park. The smallest local government water supply serves approximately 932 people. Most (49/66) of the water systems serve towns with a population range between 100 and 5,000 people. The smallest water supply system serves 30 people.

Water source and treatment

During the period under review, water supplies in the regional Hunter New England area consisted of dam (15.1%), river (25.8%), bore (51.5%) and river/bore (7.6%) systems. Disinfection methods included chlorination; a combination of chlorination, ozonation and chloramination; UV light; and silver ion. Five bore water supply systems introduced chlorine disinfection during the review period. The rate of *E. coli* detections in bore water supplies was 7.67 times higher prior to the introduction of chlorine disinfection (IRR= 7.67, [95% CI 4.24–14.87]; p=<0.0001).

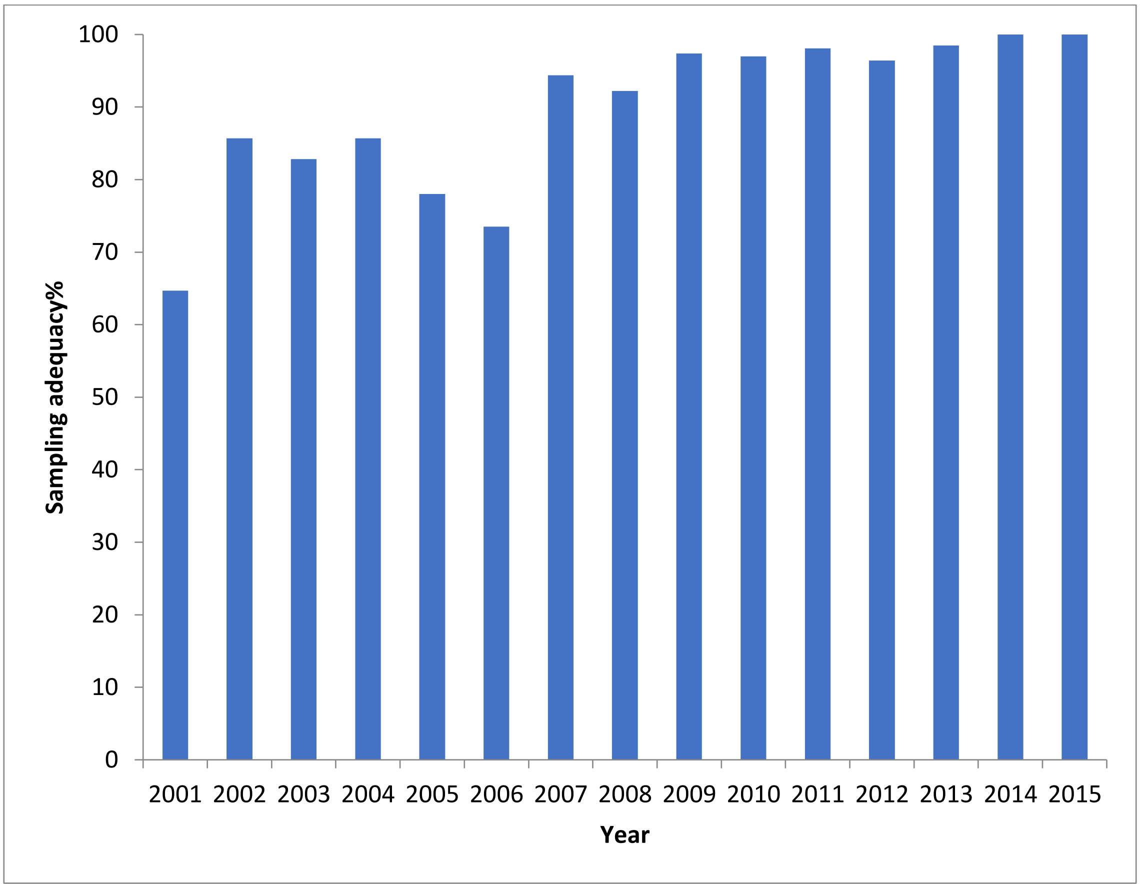
Particle removal is the filtration of water, which may be preceded by sedimentation, coagulation and flocculation, to remove suspended matter. Particle removal was commissioned at six water supply systems and disinfection (chlorination) was commissioned at five water supply systems during the review period. As of 2015, 35 (53%) water supply systems included particle removal in their water treatment processes. These 35 water supply systems serve approximately 85% of the population in regional Hunter New England. The rate of *E. coli* detections in river water supplies was 16.51 times higher prior to the introduction of a particle removal regime (IRR: 16.51, [95% CI 5.33–82.76]; p=<0.0001).

Sampling compliance

During the study period, 40,744 microbiological samples were collected and tested out of the expected (allocated) 45,224 samples. The mean sampling adequacy for the study period was 90.1%. The median sampling adequacy was 94.4%. The monthly microbiological water sampling rates were lowest in December (70.4%) and highest in March (96.5%) for all systems combined.

The rate of sampling adequacy significantly improved from 64% in 2001 to 100% in 2015 (t = 32.40, [95% CI 88.61-94.47], p=0.000 Wilcoxon T-test for Trend) (Figure 1). Sampling adequacy was significantly lower in smaller supply systems serving less than 100 people compared to those serving more than 5000 people (IRR = 0.83 [95% CI 0.70-1.00], p=<0.036).

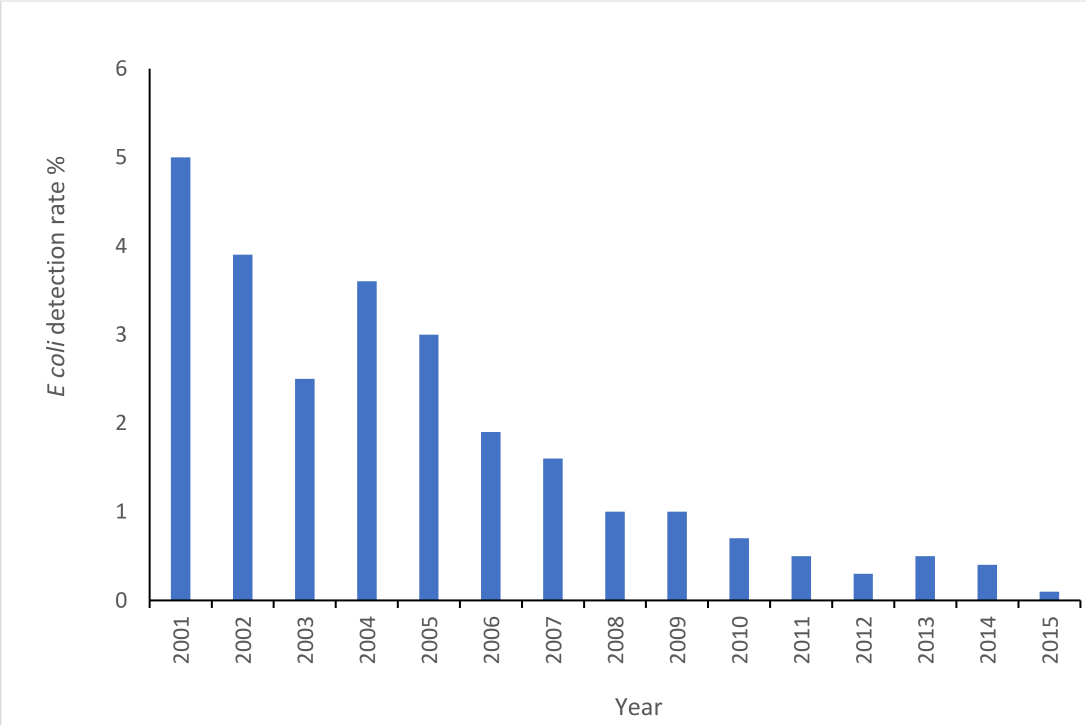
Figure 1: Drinking water rate of microbiological sampling adequacy by year all systems combined rural Hunter New England, 2001-2015



E. coli detections

During the study period, 618 *E. coli* detections (1.5%) were made in 40,744 tested samples. *E. coli* detections decreased from 5.0% of samples in 2001 to 0.1% of samples in 2015 (Figure 2). Forty water supply systems (60.6%) had a detection rate below 2.0% for the entire study period (2001-2015). *E. coli* detections significantly decreased with time (t = 4.38 [95% CI 0.88-2.56], p = 0.001 Wilcoxon T-test for Trend)

Figure 2: Drinking water *E. coli* detection rate by year rural Hunter New England, 2001-2015

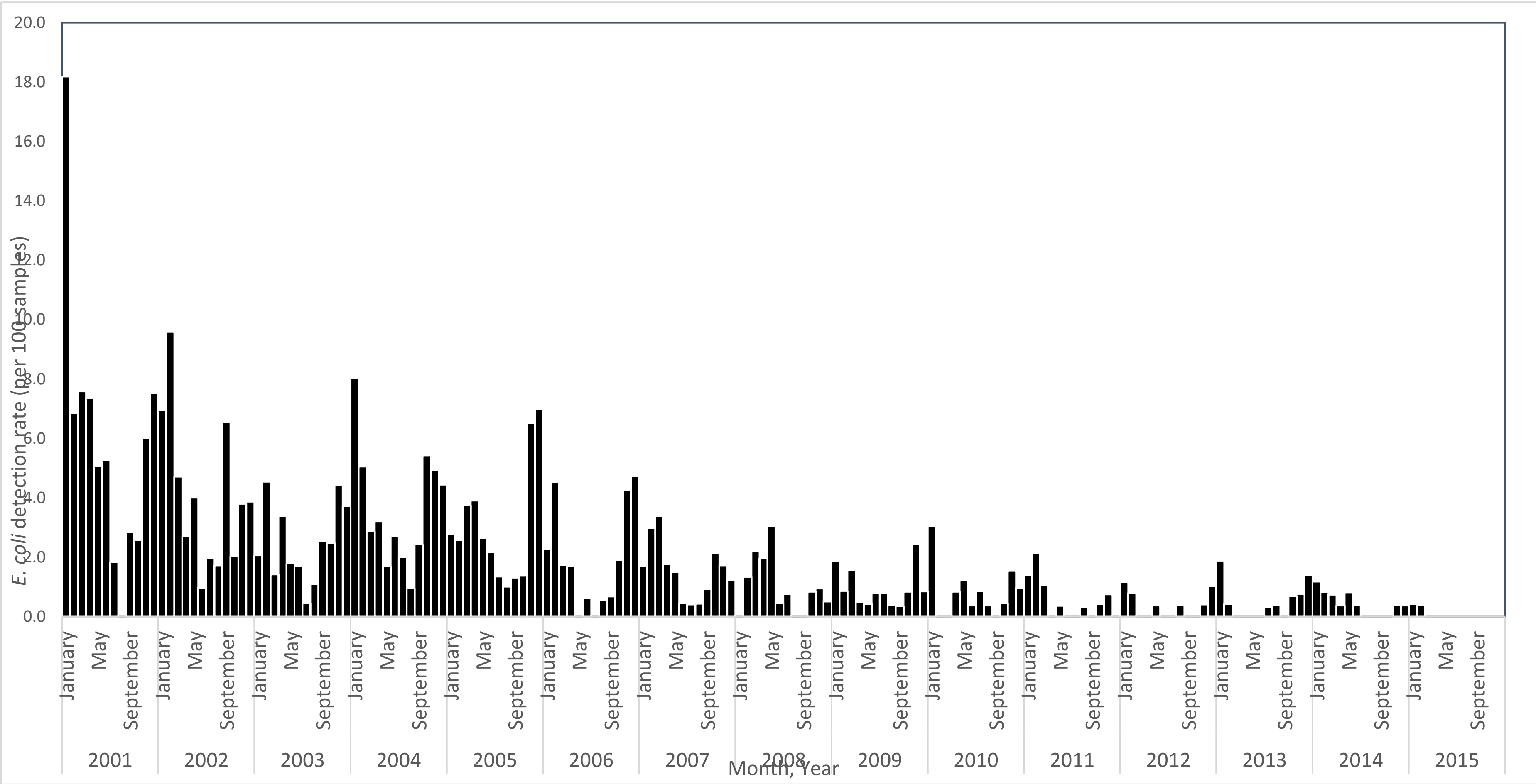


E. coli detections were significantly higher in summer (IRR 2.68 [95% CI 1.73-4.17], p= <0.0001), autumn (IRR 2.14 [95% CI 1.37-3.35], p= 0.0009) and spring (IRR 1.49 [95% CI 1.00-2.22], p= 0.0499) when compared to winter (2001–2015). Figure 3 shows a cyclical peak in *E. coli* detections during the summer months throughout the study period.

E. coli detections were 4.25 times higher in smaller systems serving less than 100 people compared to larger systems serving more than 5000 people (IRR 4.25 [95% CI 1.37-13.20], p=0.0123).

E. coli detections were highest in bore water supplies (1.88 per 100 samples), followed by river water supplies (1.63 per 100 samples), dam water supplies (1.03 per 100 samples) and mixed river/bore water supplies (0.63 per 100 samples) for the entire study period (2001– 2015).

Figure 3: *E. coli* detection by month and year regional Hunter New England, 2001-2015

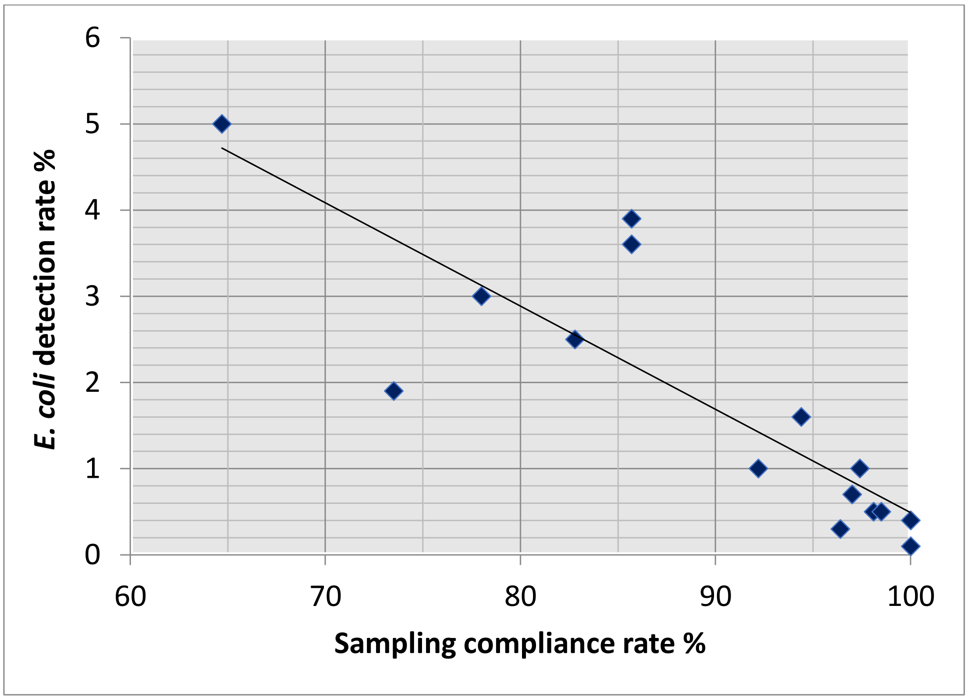


Multivariate analysis found that small populations serving less than 100 people (IR = 2.27, [95% CI 1.28-4.25], p = 0.0098), dams (IR = 2.25, [95% CI 1.19-2.26], p = 0.0126), rivers (IR= 1.81, [95% CI 1.14-2.90], p=0.0116) and treatment (IR =2.87, [95% CI 1.72-4.79], p = 0.0001) all significantly contributed to *E. coli* detections each accounting for the others as confounders.

Relationship between sampling adequacy and E. coli detections

There was a strong inverse correlation between sampling compliance and *E. coli* detection rates (Spearman's rho =-0.821; p=<0. 001) (Figure 4).

Figure 4: Correlation between sampling compliance and *E. coli* detection rates, Hunter New England region, 2001-2015

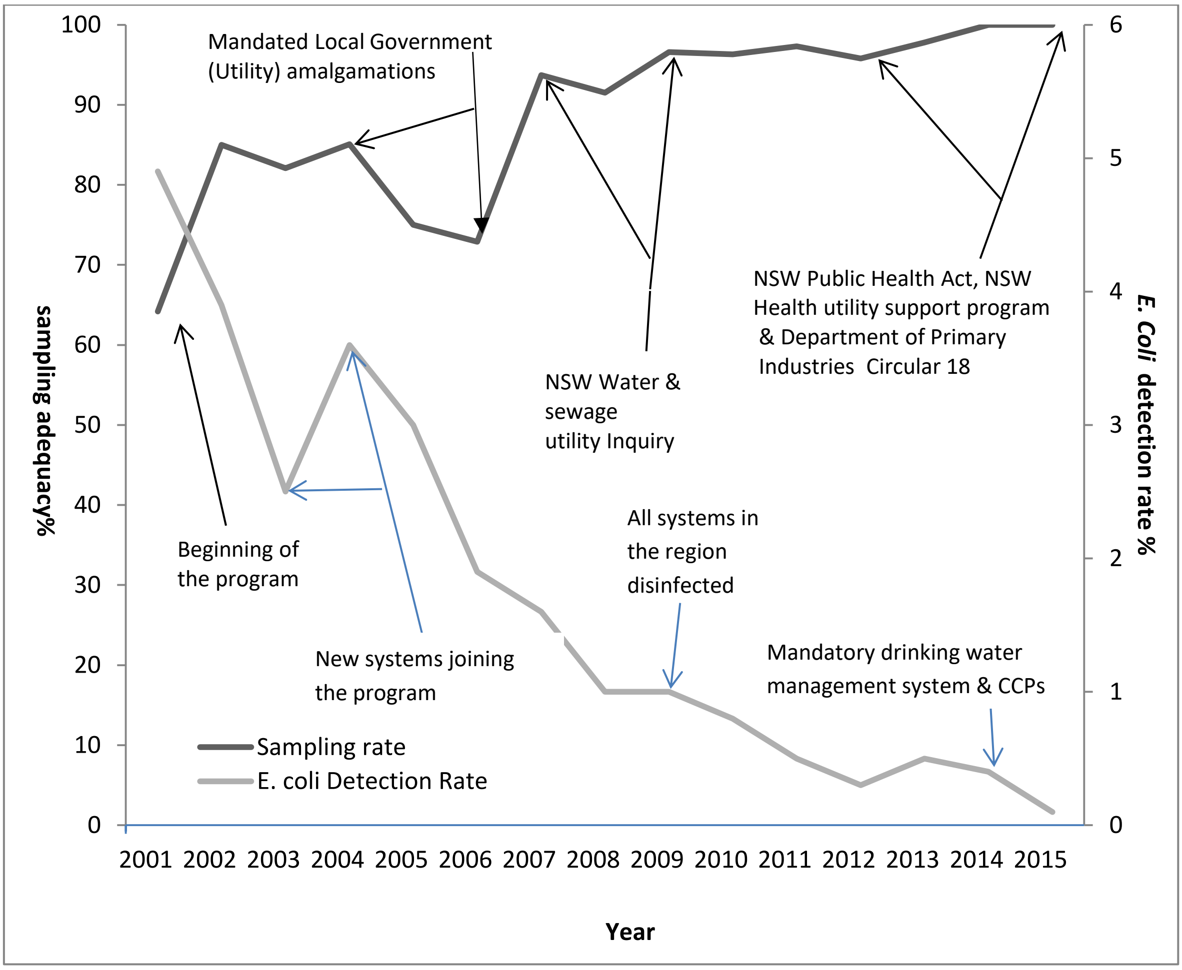


Effects of regulatory and administrative changes

Sampling adequacy decreased during the period of local government amalgamations, 2004 -2006 (Figure 5). The amalgamations caused the transfer of some drinking water systems between utilities. The total number of water utilities was reduced from 33 to 18 (55% reduction) with the creation of larger local councils. The governance of 19 out of 66 (29%) water supply systems changed to new utilities.

The *Public Health Act 2010* (NSW Government, 2010) and the mandatory drinking water management systems requirement appear to have contributed to the improved sampling adequacy and water quality *(E. coli* detections) (Figure 4).

Figure 5: Relationship between regulatory and administrative changes to microbiological sampling compliance and *E. coli* detection rates, Hunter New England region, 2001-2015



Discussion

Drinking water quality has improved significantly in the rural Hunter New England region since the implementation of the NSW Health Drinking Water Monitoring Program in 2001. Sampling compliance progressively improved from 64% in 2001 to 100% in 2015, although there were some challenges during the first years (2001-2006). In particular, there was a decline in sampling adequacy between 2004 and

2006. This was a period of local government amalgamations, with larger water utilities and sharing of technical human resources, and may explain this decline. The sampling adequacy decreased during the amalgamation period (2004–2006), only to rise in 2006 after the amalgamations were complete (Figure 5). This suggests that water utilities affected by the amalgamations required some time to adjust to the new governance arrangements and system processes. Although *E. coli* detections decreased during the same period, this may have been due to the smaller number of samples submitted for testing.

Correlation between sampling frequency and E. coli detections

The rate of *E. coli* detections decreased with increasing sampling compliance throughout the review period. The study has shown that the higher the water testing adequacy, the lower the risk of *E. coli* detections. Frequent sampling may lead to early recognition of problems in the water delivery system such as high turbidity, low residual chlorine and infrastructure malfunctions, which can then be corrected. Frequent sampling and response to the detection of *E. coli* are likely to result in increased awareness, informed vigilance, improved disinfection, reporting, governance, and improvements in the design and maintenance of infrastructure.

As a consequence of frequent monitoring and system enhancements, water quality improved and *E. coli* detections were reduced. Conversely, infrequent water sampling may result in an overestimation of water safety (Bain et al. 2014). Frequent monitoring and reporting enable PHUs to regularly review sampling compliance and work with water utilities to promptly investigate *E. coli* detections and assess risks to the community. Hence, sampling adequacy has an inverse relationship with the rate of *E. coli* detections.

Drinking water quality problems are often intermittent and can only be appropriately detected if examined frequently and consistently (WHO 2011b). Sampling programs that are designed with frequent sampling events have been reported to improve *E. coli* detections (van Lieverloo et al. 2007). In addition, a higher number of samples tested per water supply system provides a better overall indication of water quality and therefore, contributes to enhanced public health protection (Health Canada 2012).

Compliance monitoring verifies that preventive measures are effective (Sinclair and Rizak 2004). Timely follow-up of non-compliances by PHUs and the implementation of corrective actions, including improved monitoring, improved disinfection and treatment plant maintenance, have helped water utilities to comply with the Australian Drinking Water Guidelines. Utilities have acted promptly to manage potential health risks. A similar trend has been observed throughout the state (Byleveld et al. 2016). As a result of these improvements, *E. coli* detections have decreased, and sampling compliance has improved.

Small communities had lower sampling adequacy and higher rates of *E. coli* detections. Smaller communities often have limited water treatment processes and limited human resources, which can make it difficult to meet sampling compliance targets. Despite lower sampling adequacy in small communities, which was associated with increased the risk of water contamination, there were no outbreaks of waterborne disease associated with public water supply systems in the rural Hunter New England region during the study period. It is possible that outbreaks were prevented by prompt corrective actions after *E. coli* detections, such as emergency maintenance and correction of problems, increasing disinfection and issuing of 'boil water' alerts following system failure or contamination (Cretikos et al. 2010).

E. coli detections showed a seasonal trend, with more detections in summer compared to winter. Chlorine is known to dissipate faster in warmer weather than in cold weather, which may have contributed to higher detections during summer months. Rainfall trends were not assessed in this study, however, other studies have shown that faecal contamination of treated water follows a statistically significant seasonal trend with more contamination during wet seasons (WHO and UNICEF 2010).

Legislative and Administrative changes

The NSW Government Inquiry into local water utilities in 2007 provided an opportunity to establish a requirement for drinking water risk management in the *Public Health Act 2010* (NSW Government 2010). The accompanying analysis of drinking water quality in regional NSW from 2001 to 2007 (Cretikos et al. 2010) resulted in closer cooperation between the PHUs and water utilities in the HNE region. The cooperation led to faster responses to issues of *E. coli* detection, improved sampling compliance, and a greater focus on maintaining disinfection and water infrastructure integrity.

NSW Health and local PHUs have assisted water utilities across the state to implement drinking water management systems since 2012 (Byleveld et al. 2016). Water utilities have defined and implemented water quality targets for operational critical control points and have improved monitoring systems (Byleveld et al. 2016). Record keeping and communication systems have also improved since the implementation of drinking water managements systems. The use of realtime monitoring instruments to measure water quality parameters, such as disinfectant residual, had been adopted by seven utilities by 2015 (Byleveld et al. 2016). *E. coli* monitoring records in conjunction with sanitary inspections and turbidity and residual disinfection levels now form the basis of water quality verification statewide. PHUs continue to work with utilities to investigate non compliances and assess the risk to the community. PHUs regularly check the Database for sampling adequacy and work with utilities to promptly investigate any inadequacies and assess the risk to the community. The close working relationship between PHUs and water utilities has helped to improve drinking water quality and adequacy under the Australian Drinking Water Guidelines Framework.

Utilities must assess and manage multiple perception risks while preserving regulatory and consumer trust to protect health (Mobley et al. 2006; Parkin et al. 2006; Pollard et al. 2009; Doria 2010; NHMRC 2011). Cooperation between water utilities and other stakeholders is critical for drinking water safety maintenance and successful incident management (O'Connor 2002; Jalba et al. 2010). The technical task of producing drinking water lies with the water utility, but the mission of producing safe drinking water that has the trust of consumers (IWA 2004) requires the cooperative effort between the utility and the stakeholders (Jalba et al. 2014). Major stakeholders would include the various departments that may have a stake in water supply, such as public health regulators, environmental regulators, water resources agencies, consumer groups, community leadership) and the utility. Developing a productive collaborative relationship with stakeholders may be regarded as one of the critical tests of a water utility maturity in overall risk management (Williams and Hrudey 2007). Collaboration between health authorities, the water sector and consumers is required to satisfy both communities' health and cultural water perceptions (Bridge et al. 2010). Inaccurate perceptions of the potential public health threats have been shown to result in utilities not taking adequate risk management measures resulting in detrimental public health impacts (Yasar et al. 2011).

,Critical gaps in inter-agency relations (in proactivity, communication, training, sharing expertise, trust and regulation) have exacerbated previous drinking water incidents in other countries (Hrudey and Hrudey 2004; Jalba et al. 2010; O'Connor 2002). Increased interaction between drinking-water supply stakeholders can provide a valuable and supportive forum for the exchange of ideas. In the HNE region, joint training workshops and noncompliance investigations have facilitated good working relationships between PHUs, NSW Health, NSW Department of Industry Water and the respective local governments utilities.

Conclusion

The NSW Health Drinking Water Monitoring Program has resulted in the enhanced compliance of microbial sampling and improved drinking water quality in regional Hunter New England. The improvements followed performance reviews, water treatment improvements, corrective maintenance actions and regulatory changes. The inverse relationship between sampling adequacy and *E. coli* detections highlights the importance of consistent and frequent monitoring, detection, response and system enhancement to maintain water quality.

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Chapter. 4 Drinking Water Safety in Recreational Parks in Northern New South Wales, Australia

Plate 4.1 Drinking water storage reservoir, Moree, 2015 (Personal collection)

Figure 4.1 Location of Hunter New England National parks (NPWL, 2019).

4.1 Introduction

This chapter's focus is on private drinking water supplies in recreational parks. The aim of the research underpinning this chapter was to assess and improve the safety of drinking water in recreational parks by encouraging the drinking water suppliers in northern NSW recreational parks to conform to the recommendations of the *NSW Private Water Supply Guidelines* (NSW Health, 2016b). The project was conducted with the philosophy of capitalising on routinely collected data for practitioner-led research. The research was carried out by a team including health service managers, academics, park authorities and environmental health practitioners during their routine work, using participatory action research to bridge the gap between policy, research and practice.

The intended use of water supplies in many recreational parks in NSW is not always specified. In this study, water provided for public use without specifying the use, has been designated as drinking water because visitors may be tempted to drink the water of unknown intent if they are not adequately advised; there is no information about water quality; and warning signs are not displayed. Visitors may also use the water for brushing their teeth resulting in accidental swallowing, diluting cordials or washing fruits. Reports of outbreaks due to water of unknown intent, or not intended for drinking in camping sites have been reported in the USA (CDC, 2008; Yoder, 2008).

Untreated drinking water can spread water-borne gastrointestinal pathogens (Hrudey & Hrudey, 2004) and consumption of untreated water in recreational parks poses a public health threat. Drinking water supplies in recreational parks in the Hunter New England (HNE) region were not generally included in the NSW Drinking water Monitoring Program except for a limited number of holiday parks. However, all water supplied for drinking purposes in New South Wales (NSW), Australia should comply with national *Australian Drinking Water Guidelines* (ADWG) (NHMRC, 2011) and the *NSW Public Health Act 2010* (NSW Government, 2010) (Plate 4.2), irrespective of its source or where it is used.

16 Power to take action with respect to unsafe water (cf 1991 Act, s 10I)

(1) The Minister may take such action, and by order give such directions, as the Minister considers necessary:

(a) to restrict or prevent the use of unsafe water, and

(b) to bring unsafe water to such a condition that it is no longer unsafe water.

(2) Before giving a direction to a supplier of drinking water constituted under an Act, the Minister is to consult with the Minister responsible for the Act under which the supplier is constituted.

(3) In this section, ***unsafe water*** means:

(a) drinking water that the Minister suspects to be unfit for human consumption, or

(b) any other water that the Minister suspects is, or is likely to be, a risk to public health.

Plate 4.2 ***NSW Public Health Act 2010*** **(NSW Government, 2010) provision for safe drinking water**

The *Act* and *Regulation* require drinking water suppliers in NSW to develop and adhere to a quality assurance program from September 2014. The quality assurance program must comply with the Framework for Management of Drinking Water Quality (Framework) as outlined in the ADWG, and must be specific to the supply system, considering both health and aesthetic quality (taste, colour, and odour). The quality assurance program takes a preventive-risk management approach, and builds on the principles of multiple barriers, Hazard Analysis and Critical Control Points (HACCP) (Byleveld et al., 2008; NHMRC, 2011). When the water supply is not treated and the quality regularly tested, provision of onsite warning signs has been made mandatory. NSW Health has worked closely with public health units, local government agencies and industry associations to encourage private water suppliers and water carters to comply with the *NSW Public Health Act 2010* (NSW Government, 2010). Quality assurance program templates were developed and can be adapted for different water supplies, including bore, river water, rainwater systems, and carted water.

Consistent oversight is lacking when it comes to ensuring that the regulatory standards for private water supply systems are the same as those for public water supply systems (Dale et al., 2010). The 2009-2010 Guide to New South Wales (NSW) National Parks advises visitors to be self-sufficient with drinking water or to have suitable equipment and knowledge to treat untreated supplies (NPWS, 2009). The NSW National Parks Visitor Safety Policy and Procedures state that safety messages will be included on the Website and in Parks Visitors' Guides and brochures (DECCW, 2009).

Recreational parks are popular in the Hunter New England (HNE) region. From 2012 to 2014 about 23,153,952 visitors attended regional parks to enjoy picnicking and camping (Campbell, 2012). The popularity increases the scale of potential impacts for waterborne diseases among visitors. The absence of documented outbreaks should not be used as a justification for provision of unsafe water in recreational parks, and a precautionary approach is justified. There is a wide geographic dispersion of potentially infected persons from the site of exposure, and therefore cases of illness might be less likely to be identified as part of an outbreak specific to the park concerned (CDC, 2011).

4.2 Ethics

Ethics approval for the project was granted by the Hunter New England Human Research Ethics Committee (HNEHREC 13/10/16/5.06); NSW Human Research Ethics Committee (NSWHREC LNR/13/HNE/418) and James Cook University Ethics Committee (H5085). The surveys were carried out as part of the environmental health officers' normal inspections duties. The Parks authorities were sent courtesy letters explaining the objectives of the surveys. Assistance and cooperation were requested and obtained from the respective parks' officers. One officer volunteered to assist in the water sampling activities. The survey results were sent to the park authorities for feedback. Clarifications were incorporated before the publication of results.

A project proposal was submitted to the NSW Health Water Unit. The NSW Water Unit, in conjunction with the NSW Forensic and Analytical Science Service Laboratories, determined the number of samples to be submitted per month, depending on the laboratory's analytical capacity during the survey period. The project was approved on condition that the final result was reported to the NSW Health Water Unit.

Plate 4.3 Recreational attraction: Sawn Rocks, Mt Kaptur National Park, Narrabri

4.3 Research Impact

The second survey was built upon the results of the first survey, and assessed the Park authorities' response to the survey recommendations. Since 2014, water quality assurance plans (water quality management systems) are now mandatory for all private drinking water supplies in NSW. Recreational sites that provide potable drinking water now routinely monitor the quality of the available water. The Public Health Unit worked with contractors to develop quality assurance programs for five different types of private water supplies, including bore, river water, rainwater and carted water. These have been publicly shared to provide examples for other private suppliers.

Although no outbreaks have been recorded in the region due drinking water in recreational parks, it was realized that there was potential for outbreaks. The Public Health Unit has, throughout the period of this study, recommended and assisted private water suppliers to develop and implement risk-based quality assurance programs as required by the *NSW Public Health Act 2010* (NSW Government, 2010). Where the water supply is untreated or not regularly monitored or the intended use of the water is not specified, authorities are required to include such supplies in their management plans and advise visitors, and install and maintain warning signs at each water outlet. The quality assurance programs for these supplies are subject to annual reviews similar to the reticulated supplies.

The realisation that recreational parks can pause public health issues through water provision highlighted in this research study initiated a state-wide broad initiative to improve private drinking water safety. NSW Health has worked closely with local councils, government agencies and industry associations in order to promote awareness of the quality assurance program requirement for private water supplies and water carters. Updated NSW Private Water Supply Guidelines (NSW Health, 2014), and NSW Guidelines for Water Carters (NSW Health, 2012) must include mandatory drinking water quality assurance programs, water treatment fact sheets, and sample quality assurance program templates that can easily be adapted for different water supplies have been published. These actions represent a good example of beneficial policy change, with regulatory support.

The policy change involved a systems approach, which attempts to understand and mitigate the underlying vulnerabilities of recreational parks water supplies rather than concentrating on enforcing compliance with regulations despite difficulties faced by authorities. The involvement of the parks authorities in the study improved the uptake of the study findings and the translation of evidence into practice. Collaboration between the Public Health Unit and recreational parks authorities is essential to enhance public health.

The NSW Private Water Supply Guidelines have been amended to include mandatory drinking water quality assurance programs. NSW Health has worked closely with local councils, government agencies and industry associations to promote awareness of the quality assurance program requirement for private water supplies and water carters. NSW Health has published updated NSW Private Water Supply Guidelines (NSW Health, 2014) and NSW Guidelines for Water Carters (NSW Health, 2012), water treatment fact sheets,

4.4 Journal Publications

Two consecutive drinking water surveys were carried out and are presented as the following journal articles:

1. Jaravani, F. G., Durrheim, D., Byleveld, P., Oelgemoeller, M., & Judd, J. (2015). Drinking water safety in recreational parks in northern New South Wales, Australia. *Australasian Journal of Environmental Management*, *22*(4), 432-445, doi: 10.1080/14486563.2014.984782.
2. Jaravani, F. G., Byleveld, P., Durrheim, D., Judd, J., Oelgemöller, M., Butler, M., Massey, P. (Under review). Improving drinking water safety in recreational parks through policy changes and regulatory support in the Hunter New England region, NSW, Australia. *Australasian Journal of Environmental Management,* TJEM- 2017-0092.

National Parks & Wildlife Service authorities have responded to the study findings by issuing a precautionary risk management policy for drinking water provision. The policy addresses drinking water provision under significant uncertainty about drinking water quality by informing the visitors whenever the quality cannot be guaranteed. Overall, there has been a marked improvement in the availability of quality assurance programs and warning signage for public safety. These responses are evidence of regulatory support for field-based evidence generation.

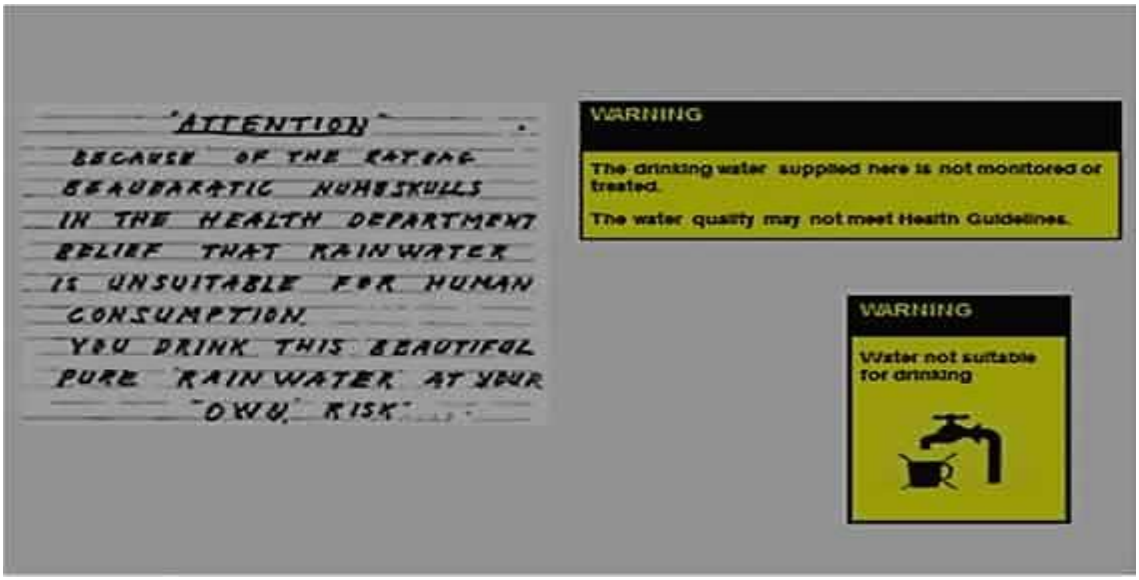

Plate 4.4 An interesting caption to a water quality information sign

4.4.1 Article: Drinking water safety in recreational parks in northern New South Wales, Australia

The cooperative and proactive approach by authorities to the survey and microbiological sample results was encouraging. The provision of monitoring and sampling results acted as an incentive to improve risk management strategies. The improvements initiated should reduce the risk of poor-quality drinking water on human health in the recreational parks in northern NSW.

Plate 4.5: Recreational attraction: Raspberry lookout, Gibraltar Range National Park, Glen Innes, NSW (Personal collection)

Jaravani, F. G., Durrheim, D., Byleveld, P., Oelgemoeller, M., & Judd, J. (2015). Drinking water safety in recreational parks in northern New South Wales, Australia. *Australasian Journal of Environmental Management*, *22*(4), 432-445, doi:10.1080/14486563.2014.984782

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Australasian Journal of Environmental Management, 2015
http://dx.doi.org/10.1080/14486563.2014.984782

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Drinking water safety in recreational parks in northern New South Wales, Australia

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The objective of this study was to assess whether the drinking water supplies in northern New South Wales (NSW) recreational parks conformed to the recommendations of the NSW Private Water Supply Guidelines. Water supplies in 57 recreational parks were surveyed to assess implementation of the Guidelines. A random sample of five parks (excluding reticulated town water supply or rainwater) was selected for microbiological sampling over a 12-month period. Additional nine samples were collected from carted water supplies. Forty-four of the 57 water supplies were untreated. *Escherichia coli* was detected in 16 of 59 monthly samples. Two of 36 treated water samples showed contamination by *E. coli* compared to 14 of 23 untreated water samples. Three of nine carted water supplies had *E. coli* at initial sampling. Thirty-four supplies had warning signs posted somewhere in the park. Twenty-one drinking water tanks had evidence of physical deterioration. No supply had a risk-based drinking water management plan. Treated water supplies had lower rates of *E. coli* detection and presented a lower risk than untreated water supplies. Survey and sampling results indicated the need for reviewing existing water quality warning signs in the recreational parks and implementation of risk-based drinking water management plans.

Keywords: private water supply; national park; rainwater; microbiological water samples; warning signs

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Plate 4.6 Recreational attraction: water rapids, Macleay River, Oxley Wild Rivers National Park, NSW (Personal collection).

4.4.2 Article: Improving drinking water safety in recreational parks through policy changes and regulatory support in the Hunter New England region, NSW, Australia

Jaravani, F. G., Byleveld, P., Durrheim, D., Judd, J., Oelgemöller, M., Butler, M., Massey, P. (Under review). Improving drinking water safety in recreational parks through policy changes and regulatory support in the Hunter New England region, NSW, Australia. *Australasian Journal of Environmental Management*, TJEM- 2017-0092.

Abstract

Recreational parks in the Hunter New England region of New South Wales, Australia, are popular. Ensuring drinking water safety in the parks requires the application of a considered risk management approach. This study evaluated the compliance of public recreational parks with the *NSW Public Health Act 2010* (NSW Government, 2010) requirements to implement quality assurance programs. Between March and August 2016, private drinking water supplies in 53 national park and four state recreational sites in regional Hunter New England were surveyed to evaluate whether the recommendations from an initial survey of 2010-2011 were implemented. The results were compared to the first survey results. NSW Health worked cooperatively with the parks management to ensure compliance with the Act and promote public health. All recreational sites had developed and implemented drinking water quality assurance programs compared to only four during the first survey. Fifty-two of 57 (91%) sites had warning signs at water outlets compared to 34 (60%) during the first survey. There were statistically significant improvements in the provision of water quality warning signs and implementation of water quality assurance programs ($p<0.0001$ McNemar Chi^2 Test) between the first and second surveys demonstrating this success of policy change, with regulatory support.

Key words

Drinking water safety, drinking water quality assurance program, national parks, private drinking water supply, recreational parks, water quality warning signs

Introduction

The burden of waterborne diseases contained in drinking water in recreational parks in New South Wales (NSW), Australia is not known. Outbreak investigations are infrequently able to determine the sources of infection and etiologic agents for gastrointestinal illness (Craun et al., 2010). The primary goal of drinking water suppliers should be to produce and deliver safe drinking water for consumers (Charrois, 2010) and there are guidelines and regulatory drinking water measures to protect public health (NSW Government, 2010; NHMRC, 2011).

The role of drinking water in endemic enteric diseases is challenging to characterise (Hrudey and Hrudey, 2004). Kirk et al. (2014) estimated that in 2010 there were 15.9 million episodes of gastroenteritis in Australia. The proportion of these diseases which are due to waterborne outbreaks was not documented. Recreational water and food contamination rather than drinking water are considered as the most likely sources of outbreaks in NSW (McAnulty et al., 1993).

There are difficulties in identifying and categorising gastroenteritis outbreaks, and in obtaining microbiological and epidemiological evidence, which can result in misclassification or underestimation of water-associated events (Dale et al., 2010). Multiple factors contribute to the ability of health authorities to recognize, investigate, and report waterborne-disease outbreaks. Only a minority of people with gastroenteritis go to a doctor, and only a minority of these provide a stool sample (Hall et al., 2006b; McAnulty et al., 1993), while other cases are mild and self-limiting (Kirk et al., 2014).

Lack of sensitivity in routine disease surveillance in detecting waterborne outbreaks has been discussed (Craun et al., 2004; Hrudey and Hrudey, 2004). Disease incubation period, location of the exposure and severity of illness are likely to influence the detection, investigation, and reporting of recreational park water–associated illnesses (CDC, 2011). Wide geographic dispersion of potentially infected persons from the site of exposure, cases of illness might be less likely to be identified as part of an outbreak (CDC, 2011). Even the widely publicised Milwaukee drinking water outbreak was initially detected by increased demand for diarrhoeal medication instead of disease notifications, due to delayed/under-notification and infrequent testing (MacKenzie et al., 1994). Studies have revealed that approximately 30% of people will seek medical attention for enteric illness (Frost et al., 1996; Hall, 2004) of which only about 20% will have confirmed tests with stool specimens (Scallan et al., 2006). Only a few selected pathogens are reportable to the infectious disease surveillance system (Hall et al., 2005, 2006b; Scallan et al., 2006).

In NSW, routine notifiable disease data captures only a small proportion of the enteric disease burden, as these are laboratory confirmed cases due to specific pathogens (Gilbert, 2008), although gastroenteritis outbreaks in institutions are also notifiable. Cretikos, Telfer and McAnulty (2008) noted that the higher rates of disease outbreaks in NSW were reported by the Public Health Units (PHU), with resources dedicated to enteric disease surveillance and control. Thus, it is difficult to precisely quantify the contributions of drinking water related disease in relation to food related or water hygiene related disease (Dale et al., 2010; Fewtrell et al., 2007). Reports of sporadic illnesses and outbreaks due to water of unknown intent or not intended for drinking in camping sites have been reported in the USA (Craun et al., 2010). Water quality management has been noted as a particular challenge in these often-remote environments (Sobey, 2006).

This project aimed to evaluate whether the recommendations from the initial survey of 2010- 2011 were implemented (Jaravani et al., 2015). The initial survey found that recreational parks in regional HNE parks had no quality assurance programs (QAPS), water quality was not regularly monitored, and where drinking water was not treated, warning signs were inadequate (Jaravani et al., 2015). The following recommendations for improvement were made:

- All recreational parks needed to have QAPs specific to the supply system.
- All recreational parks that provided treated drinking water needed routine monitoring of the quality of the water. When such water showed evidence of contamination, then appropriate warning signs must be posted by the NSW Private Water Supply Guidelines (NSW Health, 2016).
- All recreational parks that supplied water but did not treat or regularly monitor the quality of the water needed to warn visitors by the NSW Private Water Supply Guidelines.
- A uniform approach to water supplies in recreational parks was highly recommended (Jaravani et al., 2015).

Background

A preventive approach for all recreational park drinking water supplies is considered crucial because frequent monitoring may be difficult (Byleveld et al., 2009). The Australian

Drinking Water Guidelines 2011 (NHMRC, 2011) suggest that small water supply systems adhere to a management framework as much as possible, although it is recognised that some measures may not be practical or necessary especially in very small systems (NHMRC, 2011).

The ADWG provide guidance on safe drinking water (NHMRC, 2011). ADWG defines drinking water as water intended primarily for human consumption, either directly, or indirectly, in beverages, ice or a food prepared with water. Water is also used for other domestic purposes such as bathing and showering (NHMRC, 2011). The last Guiding Principle of the ADWG states that '*Ensuring drinking water safety and quality requires the application of a considered risk management approach*' (NHMRC, 2011, p. 1-3), grounded on a precautionary approach.

The *Guidelines* include a risk-based *Framework for Management of Drinking Water Quality (Framework)*, an authoritative best-available scientific guidance strategy that addresses commitment to drinking water quality management; system analysis and management; and supporting requirements and review, incorporating evaluation and continuous improvement (NHMRC, 2011) (Figure 1). The *Framework* moves away from reliance on end-point testing and encourages early identification and control of problems, thereby reducing likelihood of contamination (Byleveld et al., 2016).

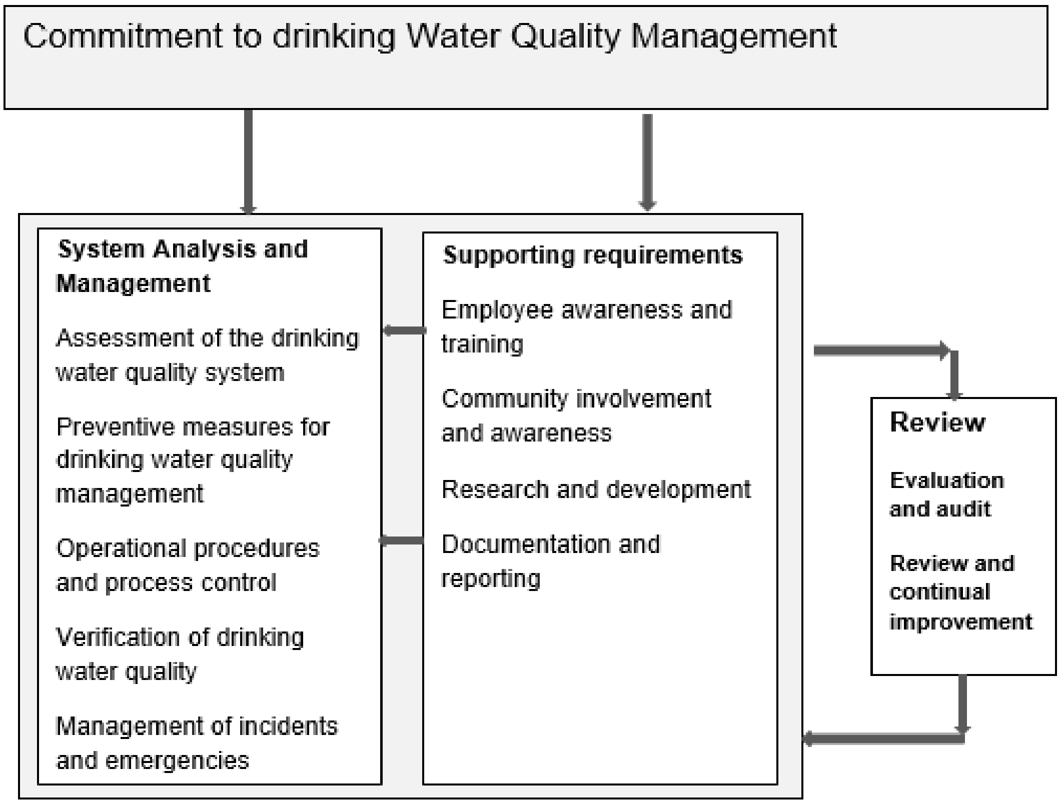

Figure 1 ***Framework for management of drinking water quality*** **(developed from the** ***Australian Drinking Water Guidelines 2011*** **(NHMRC, 2011).**

The ADWG are not mandatory or legally enforceable standards unless adopted into legislation. The New South Wales Government has adopted the ADWG into *the NSW Public Health Act 2010* (NSW Government, 2010). The NSW *Public Health Act* 2010 (NSW Government, 2010) and the NSW Public Health Regulations 2012 (NSW Government, 2012) require drinking water suppliers to develop and implement a quality assurance program (QAP) from 1 September 2014. Quality assurance programs are important tools in ensuring the safety of drinking water because they describe the water supply, identify risks, and detail the actions to be taken to protect the quality of water provided to consumers.

Water suppliers, as defined in the Act, include water utilities, private water suppliers and water carters. A private water supplier means any business or facility that supplies people with drinking water from an independent water supply excluding supplies provided by water utilities (i.e. town water) or individual household supplies (NSW Health, 2016b). This includes water from rivers, creeks, bores, dams and water from rainwater tanks.

A QAP must identify potential health risks and set out a process to control those risks in accordance with the ADWG Framework (NSW Public Health Regulations 2012) (NSW Government, 2012). The QAP should cover the integrity of the water supply system, standard operating procedures, operational and monitoring critical control points, data input, analysis and reporting and public warnings (Leask and Byleveld, 2013; NSW Government, 2012). The following matters are to be included in the quality assurance program of a supplier of drinking water:

- Identification of potential health risks associated with the supply of drinking water,
- A process for controlling those risks in accordance with the Framework for Management of Drinking Water Quality (as set out in the Australian Drinking Water Guidelines published from time to time by the National Health and Medical Research Council),
- Documentation of the identification and the process referred to under this clause - NSW Public Health Regulations 2012 (NSW Government, 2012).

For this reason, NSW Health developed the Private Water Supply Guidelines (PWSG) (NSW Health, 2016b), summarising the ADWG, assisting small operators to comply with provisions for potable water supplies. Key to the PWSG is the adoption of a risk management approach to supplying drinking water, with the support of a water quality assurance program (QAP) just as is required for public supplies. The PWSG provide guidance on operator responsibilities and obligations, protecting water quality, water treatment, monitoring and checking the supplies, and recommend public warnings were the water is not regularly monitored or treated. The PWSG are particularly useful for facilities that are not connected to reticulated supply systems such as caravan parks, camping grounds, guesthouses, roadhouses recreational parks, marinas, mines, and schools (NSW Health, 2016b). In NSW, a private water supply not intended for drinking, not treated or regularly monitored but accessible to the public, is required to be sign posted with warning or boil water advisory notices, by the NSW Private Drinking Water Guidelines (NSW Health, 2016b).

The scope of the present study was limited to camping areas and picnic sites in recreational parks served by a private water supply. Public (piped) water supplies were excluded from the analysis. The four local water utilities, serving recreational parks in the study area, have drinking water management systems which include the respective parks.

Nature of recreational parks

Hunter New England (HNE) region of NSW stretches northwest to the Queensland border from the metropolitan port city of Newcastle in the south, covering an area of 131,785 square kilometers and has a population of over 873,741 residents (NSW Health. Strategic Communications and Engagement, 2019). There are three types of recreational parks in HNE: National Parks (incorporating Nature Reserves, State Conservation Areas and Regional Parks), and State Parks (Inland Waters Holiday Parks) and State Forests. This study involved National and State Parks.

National parks are managed by the New South Wales (NSW) National Parks and Wildlife Service (National Parks) that is part of the Office of Environment and Heritage (OEH). National Parks provide recreational attractions, facilities, and tours in its parks and reserves for the visitors' enjoyment and education about nature, conservation, Aboriginal culture, and historic heritage (NPWS, 2017). Most of the parks are remote. None are supplied with town water but have independent water supplies such as rainwater tanks, rivers and bore water which may not be treated.

State Parks fall under the NSW Department of Primary Industries and are managed by NSW Crown Holiday Parks Trust through dedicated onsite park managers. NSW Inland

Waters Holiday Parks of Copeton Waters, Lake Glenbawn, and Lake Keepit are located on the shores of inland dams surrounded by rural countryside and native bushlands. Inland Waters Holiday Parks provide accommodation cabins, camping sites and picnic and barbeque areas connected to locally treated private drinking water supplies with toilets, showers and water parks (Reflections Holiday Parks, 2017). State parks are not supplied with a public (town) water supply but are supplied from private (independent) water supplies from the respective dams. The State Parks also have untreated water points for garden irrigation.

Recreational parks in the Hunter New England (HNE) region are popular. From 2012 to 2014 there were up to 6.3 million visits per year totalling some 23 million visits in the period (Campbell, 2012). The popularity increases the scale of potential impacts for waterborne diseases among visitors. However, there is no evidence of recent outbreaks affecting visitors to parks in this region. A precautionary approach is justified to ensure visitors are protected.

Public health risks

Pathogenic microorganisms, including cyanobacteria, bacteria, protozoa and viruses can cause diarrhoeal disease. Despite the limitations of surveillance systems, there are a few documented waterborne gastroenteritis disease outbreaks in Australian recreational parks (Dale et al., 2010). NSW Health has recorded some outbreaks of waterborne gastroenteritis in rural caravan parks, school camps and holiday facilities with a private water supply. A waterborne outbreak of Norovirus- like illness occurred at a caravan park with reticulated river water in southern NSW, affecting 305 visitors, with 79 hospitalised (McAnulty et al., 1993). Other outbreaks have been reported in regional NSW, the largest affecting 129 people, associated with caravan parks, school camps, holiday centres and similar facilities with a private water supply (Cowie and Byleveld, 2003; Goodall, 2000). Other occurrences may have occurred but not reported.

Hall et al. (2006) estimated that only between 8-11% of *Campylobacter* and *Salmonella* illnesses are reported in Australia and cryptosporidiosis reporting rates may be even lower due to milder symptoms (Perz et al., 1998). OzFoodNet Working Group (2015) reported that there were four waterborne disease outbreaks in Australia in 2011, affecting 100 people with five hospitalisations, but the sources were not confirmed.

In addition to the risks posed by direct ingestion of contaminated water, hand washing, teeth brushing, consumption of fruit and vegetables washed with unsafe water can also result in waterborne disease outbreaks (Cotruvo et al., 2004; Slifko et al., 2000). A survey during 2010-2011 in the regional HNE found that drinking water in some recreational park sites had high yields of *E. coli* and total coliforms (Jaravani et al., 2015).

Recreational park authorities need drinking water policies and implementation of appropriate QAPs, which may include public health warning signs (water quality information) where water quality cannot be guaranteed. NSW Health has cooperatively engaged and worked with recreational park authorities since the initial study. The engagement has ensured that appropriate QAPs are developed and implemented since 2014 when the NSW Public Health Regulations 2012 (NSW Government, 2012) requirements came into effect.

Method

The provision of water in recreational parks in the HNE region was surveyed for public health protection, with a focus on the water sources; water storage; water disinfection; provision of QAPs; warning signs; and boil water advisories.

The regional offices for the national and state recreational parks in the region were visited to discuss progress in the implementation of the recommendations of the first survey and the need for a follow up survey. Permission to resurvey the parks was obtained from the respective directors. The park authorities were interviewed to determine if the water in each park was considered potable or not, and whether the responsible management agency had any drinking water QAP.

A workshop with Public Health Unit (PHU) environmental health officers was held to review the survey check list. A purpose-made survey checklist based on the elements of the PWSG developed for the first survey was used to ensure consistency (Jaravani et al., 2015). The check list focused on water source, water use, nearby land use, availability of QAPs, routine water monitoring, water disinfection, condition of water storage tanks, the provision of appropriate warning signs and boil water advice.

Between March and August 2016, HNE Population Health Unit environmental health officers visited and surveyed the drinking water supplies in 54 national and 3 state recreational sites in HNE. Park rangers were requested to assist the environmental health officer in the survey. When water was supplied but not intended for drinking purposes, then the presence of warning signs was sought. Water samples were not collected for testing the microbiological quality of the water, unlike the previous survey. Meetings to discuss the findings were held with the respective park authorities.

In this study, all water supplies in the recreational parks were considered to be subject to the NSW Private Water Supply Guidelines. The focus was on the provision of adequate information about water quality and the provision of warning signs and/or boil water advisory notices to protect public health. All water supplied to the recreational parks was considered to be drinking water if the intent was not specified otherwise.

Based on the water sources, the results were tabulated and compared to the first survey results. The numbers of QAPs, warning signs, boil water advisories and water disinfection results were displayed as proportions of the total number of the respective water sources. The results were also expressed as dichotomous categories: Yes or No for the presence or absence of QAPs, warning signs, boil water advisories and water disinfection. The dichotomous results were analysed for statistical significance using non-parametric Chi^2 Tests when it was considered appropriate.

The work presented and reported in this study was conducted in accordance with the National Health and Medical Research Council (NHMRC) National Statement on Ethical Conduct in Human Research, 2007. The study received ethics approval from the following:

- NSW Human Research Ethics Council Approval Numbers LNR/12/HNE/246.
- NSW Site-Specific Assessment Approval Number LNRSSA/12/HNE/247.
- Hunter New England Health District Human Research Ethics Council (HNEHREC) Approval Numbers 12/08/15/5.02.
- James Cook University Human Ethics Committee (HREC) Approval Numbers H5085.

The study findings were discussed with the respective parks' regional management and a report submitted to the respective directors.

Results

The survey found that the recommendations following the first survey were generally enacted, and all recreational parks had developed and implemented drinking water QAPs. The National Parks and Wildlife Service, had declared each water supply surveyed in the study as non-potable regardless of water quality status and developed a generic QAP. State Parks had centralised management from individual trusts into one management system to fulfil the recommendation of the first survey for uniform approach to water management in the parks. The centralised management has ensured a uniform approach to water supplies and improved drinking water monitoring and safety in state recreational parks.

There were significant improvements in the provision of water quality warning signs (from 60% to 91%) and implementation of water quality assurance programs (from 7% to 100%) between survey 1 and survey 2. Nine boil water notices were replaced with water quality warning signs in accordance with the National Parks water provision policy. There were no significant changes in water storage and water disinfection between the first and second surveys. All sites that supplied water but did not treat or regularly monitor the quality of the water supplies have installed warning signs to warn visitors.

Overall, there has been a marked improvement in availability of quality assurance programs and warning signage for public safety, demonstrating a good example of beneficial policy change, with regulatory support. The improvements have enhanced public health in accordance with the NSW Private Water Supply Guidelines. Where the water is not treated or regularly monitored, warning signs enable visitors to make informed decisions.

Water supply sources

A total of 57 sites were surveyed (53 camping and picnic sites managed by NSW National Parks and Wildlife Service, and four managed by state parks). The water sources were similar to the first survey with minor changes (Table 1). One dam supply had been changed to a carted (trucked) suppl*y.*

Water source	No of Sources (1st/2nd)	Water storage type		
		PVC	Galvanised	Concrete
Dam	5/4	0	4	0
River	6/6	3	1	3
Bore	4/4	0	5	0
Carted	5/6	0	0	7
Water utility supply	4/4	0	0	1
Rainwater	32/30	10	14	12
Spring	1/1	2	0	0
Decommissioned	0/2	0	1	2
Total	57/57	15	25	25

Table 1: Recreational park water sources and storage HNE region 2010-2016

Water storage

There were 65 water storage tanks. Ten parks had more than one tank each. 25/65 (38.5%) water storage facilities were concrete tanks, 25/65 (38.5%) were galvanised steel tanks and 15/65 (23%) were plastic tanks (Table 1). Two rainwater tanks had been decommissioned by removing the water taps due to visible signs of water contamination. Procedures to improve the water quality were being considered. Six national park sites had no water storage tanks and obtained water from the neighbouring parks. Another four of the national parks had reticulated supplies from the local utilities and no storage tanks. There were no significant changes in water storage tanks between the initial and the second survey.

Thirty-two out of the remaining 43 (74%) national park sites had rainwater tanks. Thirteen out of 21 tanks that showed signs of physical deterioration with visible cracks, leaks and lichens in the first survey had been repaired/replaced. The other eight parks had old and poorly maintained rainwater tanks with holes in the roofs, overhanging tree branches and rotting leaves which could lead to microbial contamination from birds and small animal droppings (Franklin et al., 2009; enHealth, 2010).

Quality Assurance Programs

All 57 recreational sites had developed and implemented drinking water quality assurance programs (QAPs) compared to only four with QAPs during the first survey. All National Parks and Wildlife Service managed sites had developed and implemented a generic QAP. The generic QAP was reviewed by NSW Health in accordance with the NSW Public Health Regulations 2012 (NSW Government, 2012). The development of the generic QAP follows the recommendation of the first survey, which suggested a uniform approach to water management in the parks. The generic QAP may not address all the issues pertaining in individual parks which may require subsidiary management plans.

The development and implementation of QAPs, with specified improvement plans reviewed by the PHU, provides a framework for managers to regularly review the water quality for the benefit of public health. National Parks and Wildlife Service authorities have taken a precautionary risk management policy approach to drinking water provision. The policy addresses drinking water provision under significant uncertainty about drinking water quality by informing the visitors whenever the quality cannot be guaranteed.

State Parks have instituted a treated and monitored drinking water policy. All recreational sites that provided potable drinking water routinely monitored the quality of the water. State Parks had developed and implemented QAPs specific to each supply system and were reviewed by the Hunter New England Public Health, in accordance with the NSW Public Health Regulations 2012 (NSW Government, 2012). The QAPs were designed to meet the catchment characteristics and the water treatment regime for each park. Park specific QAPs allow any specific problems for the respective park to be addressed and may be easier to implement.

Water quality warning signs

Fifty two of 57 (91%) sites had warning signs at water outlets compared to 34 (60%) during the first survey (Table 2). There was a statistically significant difference between the first and second surveys ($p = 0.0001$, Pearson's Chi^2 Test = 53.94; DF = 6).

Water source	**Disinfection**		**Warning signs**		**Boil water advisory**	
	1st survey	**2nd survey**	**1st survey**	**2nd survey**	**1st survey**	**2nd survey**
Dam	2/5	3/4	1/5	4/4	0/5	0/4
River	0/6	0/6	5/5	6/6	4/6	2/6
Bore	1/4	0/4	0/4	4/4	0/4	1/4
Carted	5/5	6/6	2/6	6/6	1/5	1/6
Utility supply	4/4	4/4	0/4	0/4	0/4	0/4
Rainwater	0/32	0/30	26/32	31/32	11/32	3/32
Spring	1/1	1/1	0/1	1/1	0/1	0/1
Total	13/57	14/57	34/57	52/57	16/57	7/57

Table 2: Proportions of recreational park water points with disinfection, warning signs and boil water advisory notices by water source, HNE region 2016

Four of the national parks sites without warning signs had water utility supplies and were monitored regularly by the water supplier in accordance with their QAPs under the Public Health Regulations 2012 (NSW Government, 2012). Only one site that was supplied with rainwater did not have a warning sign. The attendant park ranger promised to ensure that the sign would be installed promptly. The four state parks had signs on untreated garden maintenance water supplies but not on drinking water because the water was treated.

National Parks camping and picnic areas had installed a generic sign regardless of water quality status. The provision of warning signs was a welcome step to advise visitors of water safety so that they could make informed decisions and protect their health. The warning sign (Figure 2), was installed at drinking water posts.

Figure 2: Generic warning sign, recreational parks HNE region 2016

The generic design of the sign was agreed by agencies and met the guideline recommendation for general water quality advice, but community comprehension has not been evaluated. The sign claims that the “drinking water” was not monitored or treated and may not meet health guidelines (Figure 2). The inclusion of the word “drinking” in the warning sign may confuse visitors that the water was provided for drinking purposes which is not the case where the water was sourced from potentially unsafe sources such as dams or rivers and not treated. The sign may be more appropriate for rain and ground water. When water was not supplied for drinking, the suggested words are: ‘Water not suitable for drinking’ by the Private Water Supply Guidelines. Rainwater consumption is not necessarily associated with a greater risk of gastrointestinal disease (Ahmed et al., 2012; Rodrigo et al., 2011).

State Parks had specific warning signs dependent upon the quality of water. Non-potable water supply points were sign posted with a ‘do not drink’ sign. One park had all untreated water supply points disconnected. The pipes were cut off below ground level, the taps had been removed and subsequently, there were no signs. There was no risk of the visitors drinking from such water points.

Boil water advisory

Nine out of 16 (56%) boil water advisory signs had been removed from river and rainwater supplies after the first survey (Table 2) and replaced with a generic warning sign (Figure 2). Seven park sites served with rainwater had a combination of the warning sign, ‘Do not drink’ signs and ‘Boil water before drinking or cleaning teeth’. The signs had a graphic sign of a tap and a crossed cup for the benefit of visitors who cannot read English (Figs 3).

The combination advisory signs warned visitors that the water was untreated or instructed visitors to boil the water before use, drinking, preparing food or brushing teeth (Figure 3). Such signs helped to protect public health because visitors were warned and advised on what to do to make the water safe for consumption, which the general warning sign did not do. There was no statistically significant change in the number of boil water advisory signs between the first and the second surveys ($p = 0.067$; McNemar Chi^2 Test = 0.67, DF =1). The provision of boil water advisory notices, especially for untreated water and rainwater, helped to protect public health. However, boiling water does not mitigate against chemical contamination and blue green algae toxins. A separate warning sign would be necessary to protect the visitors’ health in these circumstances. The PWSG recommended wording is ‘water not for drinking or bathing’.

Water utility supplies were excluded from the test because the NSW Private Water Supply Guidelines do not recommend any signs for regularly tested and monitored water supplies.

Figure 3: Boil water advisory signs, recreational parks, HNE region 2016

Water disinfection

Sixteen of 57 (28%) supplies were disinfected compared to 13/57 (23%) during the first survey. One previously untreated dam supply was provided with chlorine disinfection during the second survey, while another untreated dam supply system was decommissioned and substituted with a treated carted supply. A third dam supply system which had ultraviolet (UV) light disinfection during the first survey was changed to chlorine disinfection. Only one dam supply system remained untreated (Table 2). All State Parks had dual water supply systems: a potable supply and a non-potable supply for garden maintenance. These improvements were considered substantial given the cost in relation to the small size of the systems.

Discussion

Significant progress has been made to improve the safety of water supplies in recreational parks in the HNE region through the implementation of the multi-barrier QAPs and improving water treatment. NSW Health has worked cooperatively with the parks authorities to ensure compliance with the Act and promote public health.

Overall, there has been a marked improvement in the availability of quality assurance programs and warning signage for public safety, demonstrating a good example of beneficial policy change, with regulatory support. These improvements have enhanced public health by the NSW Private Water Supply Guidelines. Where the water is not treated or regularly monitored, warning signs enable visitors to make informed decisions — warning signs were installed regardless of the potability of the supplies and intended uses.

Previously, there was a general lack of treatment, routine testing and maintenance to improve drinking water safety in the subject recreational parks (Jaravani et al., 2015). By not routinely testing the water, authorities may not be fully aware of problems with their water supplies to the detriment of public health. NSW Health has worked cooperatively with the parks authorities to ensure compliance with the Act and promote public health. The authorities have now developed a generic QAP that include treatment, testing and maintenance whenever water is supplied for drinking (potable water).

The National Parks and Wildlife Service's generic QAP has declared the water supplied as 'non-potable' following a precautionary duty-of-care principle. The declaration may deter users from drinking the water but does not guarantee safety if the user decides to ignore the advice. In Australia, it is common practice to drink rainwater in private households such as farms and remote communities, regardless of the availability of reticulated water supply (Chubaka et al., 2017). Rainwater is considered safe if properly managed (Hellard et al., 2001; Heyworth et al., 2006; Ahmed et al., 2010; Rodrigo et al., 2011).

Quality Assurance Program

Drinking water quality assurance programs (QAPs) and public health warning signs are a way of mitigating risks associated with drinking water of unknown quality. Regardless of whether a system is for drinking or not, it still needs a simple QAP that identifies how the authorities will maintain the signs for warning consumers. Regardless of the water being designated non-potable, all the surveyed national parks adhered to the generic QAP in line with the NSW Public Health Regulations 2012 (NSW Government, 2012). The QAP addressed the elements of the *Framework for Management of Drinking Water Quality* that are relevant to the drinking water supply system. The QAP had electronically scheduled maintenance templates which enabled standard approaches for water maintenance in rain and carted water systems. However, the generic sign (Figure 2) was sometimes used for untreated river water whose quality could not be verified to be potable. At such sites, it may be preferable to warn visitors not to drink the water without some form of treatment such as boiling (Figure 3).

Converting hindsight into foresight usually prevents accidents without having to experience them (Hrudey and Hrudey, 2004). Drinking water policies cannot, therefore, be decided by the number of reported cases of waterborne enteric diseases but on the precautionary approach as it applies to environmental health risks. The Australian *Precautionary Principle* states that

> Where there are threats of serious or irreversible environmental damage, lack of full scientific certainty should not be used as a reason for postponing measures to prevent environmental degradation. In the application of the precautionary principle, public and private decisions should be guided by:
>
> 1. careful evaluation to avoid, wherever practicable, serious or irreversible damage to the environment; and
> 2. an assessment of the risk-weighted consequences of various options.
>
> (COAG, 1992 section 3.5.1)

Characterising the water supplies and quality uncertainty can provide a better understanding of the limitations of the hazard identification and risk assessment and how these limitations can be reduced (NHMRC, 2011). A drinking water quality policy is an important step in formalising the level of service to which the drinking water supplier is committed (NHMRC, 2011).

Generic warnings signs and boil water advisories

Warning signs should ensure that visitors are adequately warned about water quality. Effective communication to increase community awareness and knowledge of drinking water quality issues and the various areas of responsibility is essential (NHMRC, 2011). Even where non-potable supplies are provided, the community needs to be informed accordingly. Risk of disease is reduced if public warning notices are displayed especially if pathogens are present in the water (Chalmers, 2014).

The National Parks' default position is not to provide potable water (Park Support, Integration & Systems Team, 2016). The decision to provide potable water requires the approval of the Branch Director provided that the water is maintained to a potable standard consistent with the NPWS Drinking Water Quality Assurance Program and the NSW Private Water Supply Guidelines. In the Hunter New England region National Parks and Wildlife Service have opted to declare all water supplies in the camping and picnic recreational parks non-potable. Consequently, a generic sign has been adopted to warn the visitors about the water quality (Figure 2). The sign was adopted from the NSW Private Water Supply Guidelines to inform consumers that the quality of the water could not be assured because it was not treated and not tested. The warning signs were in some instances, insufficient or inadequate to effectively inform the visitors. For example, the generic sign (Figure 2) was used for untreated river water whose quality could not be verified to be potable. In such instances, the visitors should be warned not to drink the water without some form of treatment such as boiling (Figure 3).

The generic sign seems to be an appropriate choice in cases where the relevant authorities cart in treated town water, or where well managed rainwater supplies exist. Carted water has been found to be safe if properly managed (Jaravani et al., 2015). Heyworth et al. (2006) found that rainwater, compared to town drinking water, did not increase the risk of gastroenteritis. However, studies have shown that acquired immunity through routine exposure to low levels of pathogens probably contributes to disguising the true levels of infection (Hunter and Quigley, 1998; Macomber, 2010; Neumann et al., 2005). This may not be the case for visitors with infrequent exposure to a water supply.

Several sites had combinations of the generic warning sign, and the ‘do not drink’ and ‘boil water’ advisory sign (Figure 2). These signs are intended to assist visitors in making informed decisions, if they wish to drink the water. The chosen generic sign would not be appropriate for untreated surface water. For appropriate signage the responsible authorities should assess the risks of the particular supply system, develop appropriate actions to manage the system safely and test any messaging with members of the general public. Visitor’s compliance with advisories or warning signs has not been tested and could be low.

Visitors should be adequately informed about the quality of the water supply. National Parks and Wildlife Service regularly updates their website to provide park users with information relevant to the site or park they are visiting. Such information could include the NSW Private Water Supply Guidelines recommended warning signs if the carted and rainwater supply quality cannot be guaranteed but where the water quality and reservoir integrity are likely to be high. However, even treated carted water stored onsite in tanks can be polluted with leaves and other organic materials, containing nutrients that encourage some microorganisms to proliferate. The quality of a water supply may also vary throughout the year. Likewise, natural disasters such as floods and bushfires may heavily pollute a water source. During the warmer months the growth of blue-green algae can make drinking water from surface water sources unsuitable for human consumption. Such water sources may also be inappropriate for bathing, as high levels of blue-green algae can cause skin rashes (NHMRC, 2011).

Water disinfection

Drinking water disinfection has been found to be beneficial whenever water is intended for human consumption. When the water is disinfected QAPs would ensure that adequate residual disinfectant is maintained. State Parks have improved the quality of their water supplies by improving water disinfection and public warning systems at their four parks. National Parks have a policy to designate unmonitored drinking water systems as non-potable supplies and warn/advise visitors accordingly. Safe drinking water supplies in the parks should be recognised both as a community service and to prevent waterborne enteric disease outbreaks. The National Parks and Wildlife Service have implemented training for staff in water quality monitoring and have been progressively updating all its sites with potable water to include at least UV filtered standard. However, most of the updated sites were outside of the study area.

Although water in most recreational parks is regarded as non-potable, there is always a risk of unintentional consumption. Contaminated water can cause illness in people who drink the water or eat food that has been prepared with it. Hand washing with contaminated water may also cause enteric diseases. In the USA, during 2007-2008, there were eight outbreaks associated with water not intended for drinking and four outbreaks associated with water of unknown intent resulting in four deaths (CDC, 2011). Many parks are surrounded by animal husbandry farms and are habitats of various wild animals. There are no enteric disease outbreaks in the HNE region that have been directly linked to animal faeces in drinking water. *Cryptosporidium and Giardia* have been isolated in foxes and rabbits in the Sydney water catchment area (Cox et al., 2005; Ferguson, 2005). Mice are recognised as a reservoir for *Cryptosporidium* and *Giardia* (Moro et al., 2003). *Escherichia coli* were also isolated in mice (Singleton et al., 2005). Viable *Echinococcus granulosus* cysts have also been identified in eastern grey kangaroos, red-necked wallabies, swamp wallabies and wombats (Grainger and Jenkins, 1996; Jenkins and Morris, 2003) that are all common in the HNE recreational parks.

Studies in the USA found that diarrhoea in campers correlated with the frequency of drinking untreated water (Risk Ratio 2.4, p =0.03) (Boulware, 2004). The diarrhoeal risk ratio for inconsistent water disinfection was 0.65, p= 0.001 (Boulware, 2004). A decreased rate of diarrhoea was associated with consistent water disinfection, especially of surface water sources (p = 0.001) (Boulware, 2004). Such findings highlight the importance of adequate management of recreational park water supplies to protect public health.

Water storage

Quality assurance programs ensure that the water storage systems, particularly tanks are regularly maintained even though the majority of the water systems are non-potable. The carted and rainwater reservoirs need adequate regular maintenance, like any treated drinking water supply, to maintain the integrity and prevent contamination by birds and possums (Ahmed et al., 2008, 2010, 2012; Merritt et al., 1999). Water storage tanks have been implicated in enteric disease outbreaks due to contamination by bird (Kramer et al., 1996; Reiss and Woods, 2011), rodent, reptile (Ahmed et al., 2012; CDC, 1995; Friedman et al., 1998), and frog faeces (Parish, 1998; Taylor et al., 2000). Untreated rainwater has recently been linked to cervical lymphadenitis in children and disseminated infections in immunocompromised adults (Hamilton et al., 2017).

Rainwater was a vital source of water (60% n = 32/53) in the national parks. There is sufficient evidence in the literature to state that identified outbreaks associated with consuming untreated rainwater are relatively rare, but that *Salmonella* is the pathogen frequently implicated (Taylor et al., 2000; Ashbolt and Kirk, 2006; Cretikos, Telfer and McAnulty, 2008; Franklin et al., 2009; Falco and Williams, 2009). The fact that potential pathogens have frequently been isolated in rainwater demands appropriate management of water storage tanks and maintenance of good roof and gutter hygiene (enHealth, 2010, Evans et al., 2009; NSW Health, 2007).

Adequately maintained rainwater tanks could provide a good source of drinking water, albeit potential risks associated with drinking untreated rainwater (NSW Health, 2007; enHealth, 2010). Elimination of overhanging tree branches and other structures where possible will prevent the congregation of small animals and birds and reduce the risk of water-borne disease outbreaks (enHealth, 2010; Franklin et al., 2009; NSW Health, 2007).

The harvesting of rainwater for drinking is a global practice (Meera and Ahammed, 2006). However, some health authorities in Australia are generally hesitant to support rainwater as safe to drink, even though rainwater harvesting has become an acceptable practice (Queensland Health, 2011; NSW Health, 2007; Leder et al., 2002; Sinclair, 2007). Research studies show that there is no significant difference in risk between properly managed rainwater and improved water supplies (Hellard et al., 2001; Heyworth et al., 2006; Rodrigo et al., 2011; Dean and Hunter, 2012). To declare properly managed carted and rainwater as non-potable may be heavy-handed. The principle might be legally and administratively efficient, but not providing a necessity to the community. If visitors carry limited water, it may lead to dehydration or poor hygiene leading to other public health problems. The PHU encourages a shared regulatory approach with parks authorities and can offer training and guidance to ensure drinking water safety.

However, the stored water can contain elevated metals like copper and lead when stored for extended periods in some brass plumbing products and metal tanks (enHealth, 2018). Rainwater dissolves minerals from metal tanks and plumping systems due to its slight acidity. Recreational park authorities were encouraged to advise visitors to flush the water for about 2 to 3 minutes before drinking. The flushing would discard water standing in some copper or brass plumbing products for extended periods to protect people's health from dissolved metals (enHealth, 2018). Some of the plumping in the parks are old and may not meet the AS/NZS Standard 4020:2005.

Limitations

The study regarded all water supplies in recreational parks as drinking water supplies regardless of their intended use or potability, thus subjecting the water to the requirements of the *NSW Public Health Act 2010* (NSW Government, 2010). Consequently, the parks authorities, as private water suppliers, are subject to the NSW Private Water Supply

Guidelines and need to provide adequate information about the water quality and warning signs and/or boil water advisory notices.

This study did not assess the water quality to verify the microbiological impact of the changes made to improve water quality management. The study could have been enhanced by observation of or interviewing visitors to understand their perceptions, water supply usage and compliance with warning/advisory signs.

The study only considered water provision in governmental recreational parks, most of which supplies were declared non-potable. Assessing risks in privately owned recreational parks could have added value to the project. However, it was considered that most privately owned parks have built up caravan parks and provided food. Such facilities are generally run on commercial basis and are monitored by the local governments, according to the NSW *Food Act* 2003 (NSW Government, 2003) or the *Local Government Act* 1993 (NSW Government, 1993).

The study did not consider the impact of inorganic chemicals that may be found in untreated water. Rainwater can contain chemicals, metals, and ionic elements which may be detrimental to public health (Heyworth and Mullan, 2009; Huston et al., 2012). Rainwater samples in NSW often test positive for inorganic chemicals, but largely within established health guidelines (Kandasamy et al., 2016).

Further research is required to understand the ongoing challenges of drinking water management in recreational parks. Such challenges include catchment management (animal faeces and animal waste), contamination in the storage systems (obsolete tanks, inadequate maintenance), and the systematic monitoring of carted water quality and effects of climate change (drought and floods), but were not investigated in this study. Relying on compliance with warning signs and advisories as a means of protecting visitors against drinking water of unknown quality may not be adequate, because compliance levels can be low.

Conclusion

Providing potable drinking water in remote recreational parks can be challenging. Our study found that when the authorities were made aware of water quality issues that they readily cooperated to rectify them by improving the water quality (State Parks) and adequately advising visitors (National Parks). It is necessary to continue regular engagement with the recreational parks authorities to maintain and improve the management of water quality risks.

The outcomes of this study provide information which enables environmental health practitioners and policy makers to improve the management of risks in recreational parks and similar environs where drinking water quality is not regularly monitored or adequately treated. The similar environs include other private water supply systems such as water carters, caravan parks, outback bed and breakfast facilities, holiday resorts and school camping sites not connected to a regular reticulation supply.

Relying on warning signs and advisories as a means of protecting visitors will depend on high levels of compliance. Compliance with advisories or warning signs has not been tested. The Public Health Unit continues to work cooperatively with the Parks management through the quality assurance programs' improvement plans that aim to improve water quality management and provision of adequate public information about water quality in the parks.

More time is needed to provide drinking water that adequately complies with the guidelines and the *Public Health Act, 2010* (NSW Government, 2010) to all the parks, considering the economies of scale for the small sizes of the majority of the supplies, suitability of technology in remote wilderness areas, and the revenue collected. Health authorities are encouraged to continue to work cooperatively with the Parks management through the QAPs improvement plans and provision of adequate public information about water quality in the parks.

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Plate 4.7 Recreational attraction: water rapids, Macleay River, Oxley Wild Rivers National Park, NSW (Personal collection).

Chapter. 5 Closing the Gap: Understanding Aboriginal Community Beliefs, Perceptions and Attitudes Towards Drinking Water Supplies

"The ability to drink water that is delivered into households without fear of becoming ill may be one of the key defining characteristics of developed nations, about the majority of the world. Yet there is well-documented evidence that disease outbreaks remain a risk that could be better managed and prevented even in affluent nations." (Hrudey et al., 2006 p 947).

Plate 5.1 Special event gathering: Walhallow Aboriginal community, Caroona, NSW, 2016 (Personal collection)

5.1 Overview

Drinking water supplies in rural Hunter New England are generally safe to drink, despite some infrequent occurrences of *E. coli* detections (Jaravani et al., In review[a], JWH-D-18-00051). But, are all consumers receptive and happy to consume the water? To answer this question, this chapter discusses the opinions of the Walhallow Aboriginal community as an example of some consumers' perceptions about the drinking water supplies in the region.

Adequate quality and quantity of water are essential for drinking, food preparation and cooking, bathing, washing, waste removal and recreation. Potable water is, essential for health (Morton et al., 2010). Aboriginality is poorly reported at 76% on deaths data in NSW (Population and Public Health Division, 2012). Determining the number of Aboriginal deaths from the diseases caused by poor water quality and quantity in NSW is tricky (Morton et al., 2010). Aboriginal infants in Australia are reported to be 7.9 times more likely to die of infectious and parasitic diseases (which would include waterborne diseases than non-Aboriginal infants (AIHW, 2010). Such diseases include waterborne diseases. Aboriginal children aged 1–14 years are five times more likely to suffer from such diseases than non-Aboriginal children (AIHW, 2010). However, there are no recorded waterborne disease outbreaks due to reticulated and treated drinking water in NSW.

This study sheds some perspectives on working with an Aboriginal community to understand how environmental issues can affect the cultural drinking water perception and acceptability in a community, arguing for a policy focus and research that is inclusive of social factors in risk perception. Consumer consultation on water quality requirements and impact of aesthetic quality are recommended in the WHO Guidelines for Drinking Water Quality (WHO, 2011) and the Australian Drinking Water Guidelines 2011 (NHMRC, 2011). This study advocates for the participation of consumer representatives coupled with the whole of community consultation along the way. Early engagement and building relationships with the community and other stakeholders was paramount to build trust and relationships. The engagement began during the researchers' regular public health duties, pre-planning and project scoping. This early engagement facilitated the identification of influential community members to work with before the commencement of the project. Ample time was provided to accommodate proper consultations and discussions with the community representative bodies such as Community health workers, the Walhallow Corporation and the Walhallow Local Aboriginal Land Council who make decisions on behalf of the Walhallow community.

Working with the community in public health programs such as the Community Companion Animal's Health Program, Housing for Health, and Aboriginal Communities Water and Sewerage Infrastructure Rehabilitation Program enabled the practitioner and researchers to understand community protocols. Participating in community social programs such as National Aborigine and Islanders Day Observance Committee (NAIDOC), National Reconciliation Week, National Close the Gap Day and National Sorry Day provided opportunities to learn community protocols and develop sustained relationships. Knowledge of these protocols provided a positive foundation of trust and helped to build cultural awareness, avoid sensitive behaviours and language. The engagement and active participation of the community members as co-researchers developed legitimacy and sustained goodwill with the community. Regular communication with community representatives was paramount to the success of the project.

Aboriginal communities in urban centres of NSW get drinking water from the local water utility and have no jurisdiction over the water quality and management. Discrete Aboriginal communities in NSW are responsible for the water supply and management of the distribution system. In some communities, the local water utility, especially local governments, supply bulk water to the community boundary (Byleveld et al., 2016). The community itself manages the distribution of the water in their community. It is expected that the water quality is adequately managed to the satisfaction of the respective communities, and that communities would readily consume the water. However, when the local utility supplies the water, water quality is mainly driven by technology-driven approaches where knowledge, decision making and responsibility reside with the utility (Willis et al., 2015). Research suggests that communities are not satisfied with such setups (Pearce et al., 2008; Willis et al., 2009).This approach may be a disincentive to the community to manage the risks in the water supply because the community may not have full control of the water quality. Such situations lead to service acceptance drawbacks.

A study by the Environmental Health Needs Coordinating Committee (2008) in Western Australia showed that 35% of Aboriginal communities were not satisfied with their water supply. Werner (2009) suggests including the community's preferred technologies and implementation procedures to embrace the diversity of value positions of consumers in the management of water supplies in smaller communities. Successful service to any community requires the understanding of how technological and human dimensions interact to result in prescribed social, economic and environmental outcomes (Wills et al., 2015). Consumers can make hard decisions that utilise social and human capital to make water management plans work if they understand the risk involved (Grey-Gardiner, 2008).

Several studies on drinking water preferences in Australian communities have been carried out in urban centres of Australia where high-quality reticulated systems are present (Heyworth et al., 2006, Hellard et al., 2001, Rodrigo et al., 2010, Chubaka et al., 2017). These studies have been focused largely on individual attitudes and environmental determinants of perceptions of safe drinking water. The influence of physical environmental factors such as water hardness and taste cannot be discounted from cultural perceptions of risk (Doria, 2010) because water consumption is embedded within the physical and social environment and community satisfaction (Parkin et al., 2001; Syme and Williams, 1993). Improvements in the quality and quantity of water will not be fully appreciated if consumers continue to be suspicious and have pessimistic perceptions about their water (Spence and Walters, 2012).

Studies on drinking water in Aboriginal communities have also been carried out (e.g. Plazinska, 2003; Baile et al., 2004, Yuen and Nevin, 2006; Beard, 2009; Willis et al., 2009; Browett et al., 2012; Shepherd, 2012; Barber, 2013; Hall, 2018). The studies generally focused on supply policy, governance, regulation and funding (Willis et al., 2009; Yuen and Nevin, 2008); concerns over water quality (Beard, 2009; Hall, 2018); quality and organoleptics (Plazinska, 2003); health priorities (Baile, 2004); values and rights interest (Shepherd, 2012; Barber, 2013); and cost of supplies (Browett et al., 2012). These studies did not emphasise the influence of socio-cultural aspects of water supply to the communities.

Knowledge of traditional norms and socio-cultural practices helps to understand the definition and perception of risk and the appropriate responses to it in a specific sociocultural organisation (Douglas, 1992) especially in the context drinking water (Canter et al., 1993/1994; Finucane et al., 2000). Aboriginal communities usually exploit the provided services as societies, rather than as individuals (Pholi et al., 2009). Therefore, societal rather than individual perceptions of drinking water safety have significant implications in the development of appropriate social programs, services and policies to improve water management and risk communication (Dupont, 2010; Doria et al., 2005; Doria, 2010). Understanding the perceptions of risk have been found to facilitate the manipulation of consumer behaviours and choices of drinking water (Anadu and Harding, 2000; Doria, 2010).

Aboriginal culture is ‘strength’ and acts as a protective force for children and families (Secretariat of National Aboriginal and Islander Child Care [SNAICC] & Innovative Resources, 2009). Kinship, a central characteristic of Aboriginal culture, is a shared value system that helps people to bond with each other and gives a sense of security, trust and confidence in the knowledge that others in the local community are always there to help care for their children (Fejo-King, 2013; SNAICC, 2011).

Indigenous Australian beliefs, perceptions and attitudes originate in a system of shared values and connections between family members and the community, as well as connections to past experiences and values (Adelson, 1998). Often, they are not understood by water supply authorities. Indigenous Australians’ perceptions of health, including opinions on fresh drinking water, are closely related to culture and has been passed down through generations (Petersen et al., 2004). Accordingly, *“Aboriginal peoples’ value for water is sacred, deep and necessary for survival and is protected by lore, which provides a system of sustainable management ensuring healthy people”* (Moggridge, 2010, p. 10). Aboriginal health will only improve when holistic approaches are applied to every stage of a development program and service delivery that affect Aboriginal people, and when there is a commitment to evidence-based policy, created in genuine partnership with Aboriginal people (Pholi et al., 2009). Monitoring of water quality quantitative data and performance monitoring should continue, but we should also start thinking about how the communities we serve appreciate and exploit the services as societies, rather than as individuals (Pholi et al., 2009).

Context can provide indirect information about water quality and can lead to expectations that will strongly influence perceptions (Doria, 2010). The recent project with an Aboriginal community found that frequent clogging of hot water systems, shower roses and other electrical gadgets by calcium carbonate from hard water resulted in the community rejecting town water supplies (Figure 5.2). Contextual factors such as personal, social, cultural, economic and political factors can impart indirect information about water quality and can lead to expectations that will strongly influence perceptions (Doria, 2010). Neighbourhood satisfaction is an example of local opinion that may influence the acceptability of water quality (Syme and Williams, 1993). The belief that there are serious environmental health problems in the area of residence also can affect personal concern regarding drinking water risks (Johnson, 2003). Experience and neophobia are also known to play an important role in consumers' acceptance or rejection of new supplies (Doria et al., 2005). Expecting the community to consume the reticulated supply instead of the rainwater may be: *'trying to achieve conformity to a national culture modelled on white values thus forcing the community into an un-called for sameness, trying to negate their historical specificity as a group and reduce them to the status of disadvantaged minority*" (Deschamps and Prum, 2007 p. 2).

Plate 5.2 Calcium carbonate formed from hard water in Hot Water Systems that in part led to the concerns about drinking town water, Walhallow, Caroona, NSW (Personal collection)

5.2 Historical Background

Aboriginal people have a long and complex relationship with water resources. Before colonisation Aboriginal people acted as conservators, managers and manipulators of water resources (Lloyd, 1988). Aboriginal people were able to prevent the pollution of water, filter it before drinking, reticulate and store it to reduce evaporation (Lloyd, 1988). Water holes held, and may still hold a significant place in Aboriginal people's lives and cultures. Proximity to drinking water governed the location of camp sites and hunting grounds (Lloyd, 1988). Aboriginal people in arid areas dug for groundwater and filtered it to remove contaminants. They also carried water in bags made from animal skins when they needed to travel long distances (Lloyd, 1988).

In Australia, provision of water infrastructure to Aboriginal communities can be divided into six phases:

Phase 1

Before 1950: Government settlements and missions were established to control Aboriginal settlement and transform Aboriginal lifestyles to conform to European systems, thereby separating families and breaking the hearts and damaging the minds of Aboriginal peoples (McGrath and Toussaint, 1995). The *NSW Water Act 1912* (NSW Government, 1912) licensed water for farming, commercial use and domestic supply such as Town Water Supply. New water licences were created, permitting water to be taken from rivers and underground, but Aboriginal interests in water were not formally recognised.

Phase 2

1950 to 1970: There were national moves for churches to hand over responsibility of missions to the local Aboriginal peoples and the gradual up-take by the state governments of their responsibilities for remote community infrastructure.

Phase 3

1972 to 1989: The transfer of missions to local Aboriginal peoples under policies of self-determination and the signing of the first State–Commonwealth Bilateral Agreement dedicating funds for community infrastructure were undertaken. In 1987 the Commonwealth advocated that the State and Territories deliver to Aboriginal communities the same essential services that they provided to other non-Aboriginal communities, but the States and Territories claimed that it was too costly (Blanchard et al., 1987). The *NSW Aboriginal Land Rights Act* in 1983 (NSW Government, 1983) transferred Aboriginal reserve lands to Local Aboriginal Land Councils (LALCs), which became responsible for drinking water in communities, often without appropriate resources and technical know-how.

Phase 4

1990 to 2000: The *Water Management Act 2000* (NSW Government, 2000) recognised Aboriginal cultural and spiritual interests in water for the first time in NSW. The standardisation of drinking water infrastructure in Aboriginal communities was considered.

Phase 5

2000 to 2007: The National Water Initiative (NWI) and the mainstreaming of federal government policy for Aboriginal communities and decommissioning of the Aboriginal and Torres Strait Islander Commission (Willis et al., 2009) was undertaken.

Phase 6

2008 to present: The NSW Aboriginal Communities Water and Sewerage Infrastructure Program was created. The NSW Government and Local Aboriginal Land Councils agreed to work together to deliver improved water supply and sewerage services to Aboriginal communities (NSW Health. Office of Water, 2012). In 2009, the Commonwealth Government, New South Wales, Queensland, Western Australian, South Australian and the Northern Territory governments signed the *National Partnership Agreement on Remote Service Delivery* to fund drinking water and sewage infrastructure development and maintenance in remote Aboriginal communities (COAG, 2010).

Currently, discrete Aboriginal communities' drinking water quality management does not fall under local government jurisdiction for drinking water management. However, it is a NSW government requirement to work with Aboriginal communities to ensure drinking water quality, and hence their inclusion in the NSW Health Drinking Water Monitoring Program (Byleveld et al., 2016). The program provides Aboriginal communities in NSW with free water testing in NSW Health laboratories. The program also provides protocols for responding to contamination incidences or the failure to meet ADWG targets. NSW Health supported the development and implementation of a risk-based drinking water management system for Walhallow, through the Aboriginal Communities Water and Sewage infrastructure program.

Governance impacts drinking water maintenance in discrete Aboriginal communities along with other factors known to influence the quality of drinking water quality such as location population size, and water source (Graham, 2002; Hrudey, 2008). The divergence between the drinking water governance actors contributes to the drinking water safety concerns of some communities. Utilities provide bulk town water supply to the communities but they are not obliged to maintain the distribution system. The Local Aboriginal Land Councils (LALC) are responsible for the day-to-day operation and maintenance of town water supply systems but have no resource capacity to do so. NSW Health provides legislative governance and free town water testing. The introduction of the NSW Aboriginal Communities Water and Sewerage Infrastructure Improvement Program in 2009 brought in the NSW Health. Office of Water to oversee the town water infrastructure requirements for the discrete communities.

Local government incorporated (non-discrete) communities only have NSW Health. Office of Water, NSW Health and Local Government as the three main governance stakeholders. Despite their complementary roles, it is hypothesized that each stakeholder has own interests in developing solutions to the provision of safe drinking water to the communities. Each stakeholder has own legislative tools with the Australian Drinking Water Guidelines as the main bridging link. The different legislative tools have potential to create silo mentality (Fenwick et al., 2009). A silo mentality is a mindset which creates breakdown in communication, co-operation and co-ordination with external parties resulting in disjointed, disconnected and detrimental ways of working. A silo mentality can be divisive between organisations and is most often manifested as a communication barrier (Seville, 2006). Actors work independently without regard of how their policies and actions affect other actors.

The incorporation of Aboriginal communities in the NSW Drinking Water Monitoring Program and the introduction of the NSW Aboriginal Water and Sewerage Program has created this alignment in the provision of safe drinking water to Aboriginal communities. The unison participation of the LALC, NSW Health. Office of Water, Population Health Unit and local utilities to deliver safe drinking water to discrete communities in NSW has alleviated the silo mentality. Drinking Water Management Systems have been developed and incorporated into the local utility systems to create a holistic approach to the management of water supplies so that each actor acts in alignment with water safety objectives.

5.3 Research Impact

This chapter outlines the potential for the research model to be adapted for the broader benefit of Aboriginal communities throughout NSW and Australia, while upholding flexibility to tackle local public health priorities. At Walhallow, the softening of drinking water has now been prioritised by the NSW Government by means of the Aboriginal Water and Sewage Program. The Program encourages the community to utilise the town water supply service. The community is looking at ways to improve rainwater maintenance for those who may wish to continue drinking rainwater.

The positive attitudes of the participants and the Local Aboriginal Land Council towards improving drinking water quality and their willingness to participate in drinking water governance are important enablers for the promotion of the consumption of treated water supply in the future. Culturally appropriate public health projects are required to promote the consumption of treated and routinely monitored drinking water supported by local Aboriginal communities.

Communities would additionally benefit if practitioner-researchers were supported and encouraged to work with policy makers, academics and the communities in order to utilise research methods that provide evidence-based answers to public health questions that matter to the respective communities. NSW Health funding for drinking water quality management should be extended to embrace such schemes to improve the public health benefit of the safe water supply programs in rural and remote communities in NSW. Participation in community cultural events to promote such projects enhances cooperation (Plate 5.3).

Plate 5.3 Larakia Aboriginal cultural dance at the 8th National Aboriginal & Torres Strait Islander Environmental Health Conference, Darwin, September 2011 (Personal collection).

5.4 Journal Publications

Governance of drinking water in Aboriginal communities cannot be comprehensive without active engagement of the communities involved. Greater understanding of cultural issues, perceptions, and behaviours towards drinking water quality must be sought. In the current study, working with Aboriginal peoples helped us to gain a shared understanding about the quality of the community's drinking water supplies, the advantages of consuming water of assured quality, and the benefit of exploring community concerns about reticulated water supplies. Such understanding will inform the next steps in working with the Aboriginal communities to improve drinking water safety.

Health authorities are generally hesitant to support rainwater as safe to drink even though rainwater harvesting has become an acceptable practice (Leder et al., 2002; Sinclair, 2007). Epidemiology often seems more concerned with modelling complex relationships among risk factors than with understanding their origins and implications for public health (Krieger, 1994). It is prudent to identify and address the persistent social and economic issues that affect public health (Hofrichter, 2006). In this study, participants identified parental influence as the main reason why rain water is trusted over town water. Although water safety and organoleptics are issues of concern to the participants, and parental influence was paramount. Addressing water quality without parental influence will not solve the problem. A participant emphasised trust in rain water by saying, ““Because we have got dead frogs and that in. It doesn’t worry me I still drink it”.

The influence of interpersonal experiences on perceptions and behaviour seemed to be strong among the participants. Generally, participants drew personal implications from their general views of societal culture. “We have been told not to drink the hard water” and “…you grew up with rain water and naturally you always drink rain water first”. Educating parents on the benefits of drinking water of known quality will definitely filter down to the children. A participant described how hard it is to get out of a habit instilled by one’s parents, “I was always brought up, like it is hard to get out of your habits, when you are used to rainwater”. Influence that is passed from generation to generation becomes a culture.

Plate 5.4 Consumer preferences - despite indications of rainwater contamination consumers still prefer rainwater to town water: Types of rainwater tanks, Walhallow Aboriginal community, Caroona, NSW 2014 (Personal collection)

5.4.1 Closing the Gap: the need to consider perceptions about drinking water in rural Aboriginal communities in NSW, Australia

This publication formed the basis for the research study by building the foundation for the need for the research. Policy makers, the community and academics understood the need for participatory action research by participating in the problem definition and co-authoring.

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Perspective

Closing the Gap: the need to consider perceptions about drinking water in rural Aboriginal communities in NSW, Australia

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Key points

- Water plays a vital role in the cultural, spiritual, emotional and physical wellbeing of rural Aboriginal communities
- Provision of drinking water may be futile without appreciating the unique cultural, historical and socioeconomic factors associated with Aboriginal communities
- A new perspective on drinking water is needed by public health authorities and drinking water providers to actively engage with the communities they service
- Reducing public health risk due to drinking water of unknown quality will help to close the gap between Indigenous and non-Indigenous Australians' morbidity and mortality rates

Abstract

A crucial objective of the Australian Government's Closing the Gap program is to improve Aboriginal health, and to achieve morbidity and mortality rates similar to those for non-Indigenous Australians. Reducing public health risks due to drinking water of unknown quality will help to close the gap.

Factors such as hardness, taste, colour and odour of water may influence perceptions of risk and quality. Increased contact and familiarity with a hazard is associated with individuals becoming desensitised and habituated to its presence, so that their risk judgements may reflect their behavioural experiences. Consumption of water of unknown quality, such as rainwater, instead of treated town water in Australian Aboriginal communities may be a community norm, a part of a community's culture or a result of lack of trust in government water suppliers.

Partnerships between service providers and communities can ensure that the service is responsive to community needs, is conducted in a culturally appropriate manner and is beneficial to the community. Governance of drinking water in Aboriginal communities cannot be comprehensive without active engagement of the communities involved, and greater understanding of cultural issues, perceptions and behaviours towards drinking water quality. This Perspective article reviews the literature to shed light on the need to consider New South Wales (NSW) Aboriginal perceptions about drinking water and its acceptability. We urge more dialogue and research, and a policy focus that includes partnerships with discrete NSW Aboriginal communities to develop a deeper understanding of perceptions of drinking water and encourage consumption of safe water.

Introduction

The need for access to safe drinking water is an important ongoing public health issue globally, including in rural areas of Australia.[1] Poor water supply and sanitation contribute to a higher incidence of many diseases, including diarrhoeal disease, acute respiratory infection, skin infection and hepatitis B.[2]

Aboriginal people, especially in rural Australia, have ongoing strong connections to water, with water playing a vital role in communities' cultural, spiritual, emotional and physical wellbeing.[3] Reports discussing Aboriginal traditional stories relating to water highlight the importance of water to Aboriginal people. Beliefs and ideas associated with water can be linked to the beliefs of Aboriginal people about how the world attained its present form and shape[2], and Indigenous communities understand that water has spiritual and living attributes. Water is valued not only for what it can provide humans, but also for what it is in itself.[4]

Aboriginal communities' strong connection to water can mean that the provision of drinking water may be futile without an appreciation of the unique cultural, historical and socioeconomic characteristics of communities.[1] Concerns about the safety and quality of drinking water may also be a proxy for other social and community concerns.

This Perspective article is a review of the literature to highlight the need to consider New South Wales (NSW) Aboriginal perceptions about drinking water and its acceptability. We encourage more dialogue, research and a policy focus that includes partnerships with discrete NSW Aboriginal communities to develop a deeper understanding of community perceptions about drinking water.

Recognition of Aboriginal values

A key step in improving water governance in Aboriginal communities is to ensure that Aboriginal people's values and interests about water are better recognised and more clearly incorporated in decision making processes.[5] In the past, Australia has not systematically incorporated community views and knowledge on issues concerning management of water demand, development of water sources and water allocation.[6] Australia's approach to access to water for Indigenous people appears to be inconsistent, ad hoc and underdeveloped. Australia is one of only two member states of the Organisation for Economic Co-operation and Development that have not acceded to the World Health Organization's recommendation that all countries have national, legally binding standards for drinking water quality.[7] It has been argued that Aboriginal Australians are likely to face a higher degree of competition and contestation over water in the absence of a policy or legal framework that prioritises Aboriginal community rights and interests.[8]

However, the National Water Initiative represented a substantive change, and a step forward, by explicitly recognising Aboriginal communities' interests in water.[9] The Initiative stresses that access to water for Aboriginal people should be achieved through a planning process that:

- Includes Aboriginal community representation in water planning
- Takes into account the possible existence of native title rights to water in the catchment and aquifer area
- Potentially allocates water to native title holders
- Accounts for any water allocated to native title holders for traditional purposes
- Incorporates Aboriginal social, spiritual and customary objectives and strategies for achieving these objectives. Such objectives include connections to secular and sacred water sources, emotional wellbeing, and rights to good health for individuals, families and communities.

These points emphasise environmental flow and Aboriginal access to water, but do not specifically consider the value of drinking water within the social, spiritual and customary objectives. An assessment of the impact of the National Water Initiative has reported a negligible effect on the distribution of water to Aboriginal people.[6]

NSW Government initiatives

The desire to provide safe and adequate drinking water to Aboriginal communities in NSW is evidenced by a number of programs, including:

- NSW Health's introduction of the Drinking Water Monitoring Program in 2001
- Improved support programs for drinking water quality management systems
- Establishment of the Aboriginal Communities Water and Sewerage Program
- The Housing for Health program
- Requirements of the NSW *Public Health Act 2010* and Public Health Regulation 2012.

These programs are dedicated to monitoring drinking water and maintaining the water supply infrastructure to ensure safe, reliable and sustainable water supplies through the development of water quality assurance plans.

Since 2001, NSW Health has been monitoring public water supplies in discrete Aboriginal communities. Reports indicate that the water generally meets the microbiological standards of the *Australian drinking water guidelines* (2011). There have been no waterborne disease outbreaks or 'boil water' advisories due to drinking water contamination in NSW Aboriginal communities since 2001. However, many people with gastroenteritis may not seek medical attention, especially if the illness is minor and self-limiting.[10] NSW drinking water monitoring data show that levels of nonhealth properties of water, such as total hardness and total dissolved solids, are high in most of the water systems. Water hardness may be the main reason that most communities prefer rainwater to reticulated supplies.

Have these programs and legislative developments changed the attitudes, behaviours and perceptions of Aboriginal consumers towards the acceptability of water supplies? The most probable answer is "no". It has been argued that throwing money at a problem without the money being guided by those who understand what is required will achieve little, and may even be counterproductive.[7] In Camarines Sur, the Philippines, in 2012, it was found that 77% of villagers who had access to chlorinated water chose to drink from untreated wells that were contributing to a cholera outbreak, despite the resulting increase in cases and deaths from the disease.[11] Villagers only agreed to drink treated water after improved health education that took community perceptions, attitudes and behaviours into account.

Studies in Canada have indicated that people in First Nations communities often experienced greater health risks than those living in urban areas, despite government programs similar to the drinking water programs in NSW.[12] Despite financial and technological investment, the governance and management structures did not appear to significantly reduce the gap in service standards. Choices about drinking water consumption are governed by a complex set of factors related to sensory perception; risk perception; and economic, psychological and social issues, including media reports and marketing messages.[13] Walters and colleagues recommended exploring social or other underlying determinants of risk, such as community perceptions of the problem, to allow better mitigation of the risk.[12]

Local Aboriginal knowledge

Developing appropriate drinking water programs requires incorporating local Aboriginal knowledge into how drinking water is, and has been, provided in Aboriginal communities. Knowledge of how communities are socially and historically connected to drinking water, their reasons for valuing water, their perceptions of drinking water quality, and the degree of satisfaction with drinking water management and governance can shape people's behaviours and choices.[14] Poor perceptions of drinking water safety have significant implications for the development and improvement of drinking water management programs and public health risk communication. For instance, poverty, poor perceptions and insecurity of drinking water are associated with higher consumption of tap water substitutes, such as costly sugary beverages and bottled water; this aggravates related diseases such as diabetes and obesity in Indigenous communities.[15]

A deeper understanding of how drinking water is perceived and how it can be supplied must be gained in ways that respect the history and culture of the community being served. Considerable survey research has been carried out to investigate the concerns and attitudes of Aboriginal people about environmental water.[2] There is often an inherent, but untested, assumption that the provision of environmental flows to meet aquatic ecosystem requirements protects water interests for Aboriginal people. In 2011, the National Water Commission found that most jurisdictions had improved their consultation with Indigenous communities, but they had failed to develop effective strategies for incorporating Aboriginal social, spiritual and customary objectives in water plans.[9]

In Trout Lake, Canada, the development of a water consultation tool to better account for, and improve, the articulation of community water values (material, relational and subjective) during consultation processes was identified as the most useful application of the water value information gathered from community interviews.[5] A water consultation tool is a record of communities' voices on water interests, to formulate and communicate a clear message during consultation processes relating to water.[5] The tool helps to evaluate the amount of attention that a community places on a water governance issue, to accurately account for community members' water values in decision making about drinking water policy.[5] Water suppliers' perception of the issue tends to overestimate consumer satisfaction and underestimate the level of importance consumers place on water safety.[16] Acknowledging the value of Aboriginal people as affiliates in health issues supports best public health practice.[16]

Another important factor may be low levels of trust in government water providers, because of how communities have been treated and are currently being treated by governments. Issues about drinking water – for example, stories of intentional poisoning of drinking water supplies in the past – need to be better understood to support health programs in rural areas. When considering drinking water, people mostly prefer what they know, since it becomes the custom and the standard by which quality factors are judged. Factors such as hardness, taste, colour and odour influence perceptions of risk and quality. Mobility does not appear to influence perceptions of safe water, but, in the First Nations of Canada, regional variations were found in perceptions of safe water, by urban, rural, provincial and territorial divide, as well as intra-Aboriginal diversity.[1] Communities with poorer wellbeing were more concerned about the safety of their drinking water than communities with moderate wellbeing.[1]

Halpern-Felsher and colleagues argued that increased contact and familiarity with a hazard is associated with individuals becoming desensitised and habituated to its presence, so that risk judgements reflect behavioural experiences.[17] The risks that accompany hazards become normalised and are consistent with "the normalisation of risk". Variations of risk and experience are likely to occur across Australian Aboriginal communities that represent a variety of contextual and institutional factors at the community level. Thus, the consumption of water of unknown quality such as rainwater instead of treated town water in Australian Aboriginal communities may be a community custom rather than part of a culture or a lack of trust in government water suppliers.

Closing the Gap

In many isolated Aboriginal communities where ongoing water safety is a pressing social issue, perceptions may be different from those in larger communities that are supplied with safe town water that is highly regulated and monitored. Even in communities with supplies that meet the *Australian drinking water guidelines*, researchers have found that an isolated incident of water quality failure in the past could create long-lasting suspicion towards the water. A crucial objective of the Australian Government's Closing the Gap in Indigenous Disadvantage program is to improve Aboriginal health to achieve morbidity and mortality rates similar to those for non-Indigenous Australians. Closing the Gap is a formal commitment developed by the Australian Government to reduce Indigenous disadvantage with respect to life expectancy, child mortality, access to early childhood education, educational achievement and the achievement of Indigenous health equality within 25 years.[18] One sure way to support improved health outcomes of Aboriginal communities is to address drinking water quality and sanitation.

Illness related to drinking water contamination can lead to substantial morbidity, mortality, community anger and detrimental economic impacts.[19] Safe water supplies present a significant challenge, because communities may prefer untreated water sources, such as rainwater, to town water that meets the *Australian drinking water guidelines*. Service providers and communities can work together to generate better understanding of, knowledge of, and solutions to, drinking water problems. These partnerships are a way of ensuring that the services are responsive to community needs, are conducted in a culturally appropriate manner and are beneficial to the community.[20] Aboriginal people bear the knowledge and some of the responsibility to care for the waters upon which they depend for survival.

Conclusion

A new perspective on drinking water for rural Aboriginal communities is needed by public health authorities and drinking water providers. Research with Aboriginal communities to develop a deeper understanding of community norms, customs and perceptions relating to drinking water is crucial to support needs for cultural environmental water and drinking water. Water is an intricate part of life that has immense social, cultural and economic importance. Reducing public health risk due to drinking water of unknown quality will help to close the gap. Governance of drinking water in Aboriginal communities cannot be comprehensive without active engagement of the communities involved, and greater understanding of cultural issues, perceptions and behaviours towards drinking water quality. Understanding environmental water needs alone is not enough to close the gap.

Competing interests

None declared

Author contributions

FGJ designed and wrote the manuscript. PDM and JJ edited the manuscript. JA and NA edited the manuscript for cultural appropriateness.

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5.4.2 Working with an Aboriginal Community to understand drinking water perceptions and acceptance in rural NSW

A participatory action research project involving the community, policy makers and academics was undertaken to better understand community perceptions about drinking water provision in the community. Community engagement in the research project identification, planning, implementation and evidence translation was a critical determinant of project success.

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Working With an Aboriginal Community to Understand Drinking Water Perceptions and Acceptance in Rural New South Wales

Abstract
This study explored the Walhallow Aboriginal community's experiences with drinking water to gain a shared understanding about community concerns and to develop ways to address these concerns together. There is a strong connection between people and water, as well as a need to appreciate the social factors associated with the unique cultural and socioeconomic factors that the provision of drinking water has for Aboriginal communities. We used a mixed method design within a community-based participatory action Research (PAR) framework. Water hardness and parental influence were the key factors associated with participants' decisions to drink rainwater. This study provides important insights for water supply authorities when assessing health risks and when choosing appropriate mitigation measures for water quality improvement programs in Aboriginal communities.

Keywords
Aboriginal, community perceptions, drinking water, community experiences, mixed method research design

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Disclaimer
This article may contain information obtained from deceased persons. The information could upset some people; however, the authors wish no disrespect or distress to the respective families and the community.

The views and positions expressed in this article are those of the authors and are not necessarily representative of NSW Health.

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Working With An Aboriginal Community To Understand Drinking Water Perceptions and Acceptance in Rural New South Wales

Aboriginal Australians have a significantly higher incidence of many diseases, which occur with greater severity, compared with other Australians (MacRae et al., 2012). Mortality rates for Aboriginal Australians are almost twice as high as for non-Aboriginal individuals (Aboriginal Institute of Health and Welfare [AIHW], 2011). There is a growing impetus to identify and address the determining factors of this health disparity, with the overall aim of "closing the gap" and improving the health of Aboriginal Australians (Council of Australian Governments [COAG] 2007). However, the focus thus far has mainly been on lifestyle-based factors such as smoking and alcohol consumption (Vos, Barker, Stanley, & Lopez, 2007) at the expense of environmental health factors like drinking water quality.

A crucial objective of the Australian Governments' Closing the Gap program is to improve Aboriginal health to achieve morbidity and mortality rates similar to those for non-Indigenous Australians. Low perceptions of drinking water safety can lead to other social issues for Indigenous people's health such as obesity and diabetes and can contribute to economic impoverishment with high costs of bottled water and soft drinks. Reducing public health risks due to the drinking water of unknown quality will help to close the gap. This study aimed to gain a deeper understanding of how Aboriginal communities are socially and historically connected to drinking water, their perceptions of drinking water quality, and the degree of satisfaction with drinking water management.

Australian Aboriginal and Torres Strait Islander Population

The Indigenous populations of Australia are referred to as Aboriginal and Torres Strait Islanders. The term Aboriginal is used in the state New South Wales (NSW) to reflect that the First Nations Peoples in this state are Aboriginal (Australian Museum, 2015).

The population of Aboriginal and Torres Strait Islander peoples in 2014 was 713,600 (3% of the Australian population), of which 220,902 (31%) lived in NSW (AIHW, 2015). Twenty-eight percent (60,862) of the Aboriginal population in NSW live in the Hunter New England region, of which 21% live in remote areas compared to 2% of the non-Aboriginal population (Primary Health Network [PHN], 2016).

The current health status and challenges can be seen in the estimated gaps in life expectancy. Currently, life expectancy for Aboriginal and Torres Strait Islander people is 69.1 years for males—10.6 years lower than that of non-Aboriginal males (79.7 years)—and 73.7 years for females—9.5 years lower than that of non-Aboriginal females (83.1 years; Australian Bureau of Statistics [ABS], 2013).

Policy Context: NSW Drinking Water Policy and Regulation

It is recognised that policy frameworks involving Aboriginal peoples should recognise Aboriginal knowledge, as well as the right to self-determination and participation in decision-making (Black & McBean, 2016). This recognition must also include drinking water. Good water management requires an understanding of Aboriginal peoples' values and interests in water, and acting to support and protect those interests (Barber, 2013). In Australia, research has shown that Aboriginal and Torres Strait Islander peoples are keen to contribute their knowledge and to see their values recognised in water allocation decisions (Jackson, Tan, Mooney, Hoverman, & White, 2012).

In the state of NSW, government policy directs that the responsibility to provide safe drinking water rests with each water supplier (Byleveld et al., 2016; New South Wales Public Health Act, 2010). NSW Health is the public health regulator of drinking water in NSW. The NSW Public Health Act (2010) and the NSW Public Health Regulation (2012) require water suppliers to develop, implement, and adhere to drinking water quality assurance programs that address the Framework for Management of Drinking Water Quality in the *Australian Drinking Water Guidelines* (ADWG; National Health and Medical Research Council [NHMRC] & National Resource Management Ministerial Council [NRMMC], 2011). A quality assurance program describes the water supply, identifies risks, critical control points, and details the actions to be taken to protect the quality of water provided to consumers.

As part of the NSW Health Drinking Water Monitoring Program (NSW Health, 2005), NSW Health works with Aboriginal communities and local water utilities to monitor drinking water safety. The program provides free routine testing of drinking water for microbial indicators and physical and inorganic chemical characteristics (Byleveld et al., 2016), as well as protocols for responding to contamination incidences or test results that do not comply with the ADWG targets (NHMRC & NRMMC, 2011).

Since 2008, the water supply and sewerage systems in 61 discrete Aboriginal communities have been improved by the implementation of the Aboriginal Communities Water and Sewage Program (ACWSP). A discrete Aboriginal community in NSW is one parcel of privately owned Aboriginal land that is predominantly inhabited and managed by Aboriginal people (AIHW, n.d.; Henderson, Byleveld, Standen, & Leask, 2016). The ACWSP is a partnership between Aboriginal communities, the NSW government, and the NSW Aboriginal Land Council. The ACWSP aims to improve health and well-being by providing services equivalent to the standard expected in the wider community (Byleveld et al., 2016).

Under the ACWSP, drinking water quality assurance programs were implemented in many discrete Aboriginal communities well before the 2010 NSW Public Health Act requirement. Experienced service providers (generally local councils) are contracted under formal service agreements to provide water and sewage support services (Henderson et al., 2016). Specialist contractors review critical control point performance, risk assessment findings, and improvements. Aboriginal community water management plans were integrated into utility drinking water management systems (Byleveld et al., 2016).

The Importance of Water to Aboriginal Communities

There is a strong and lasting connection between Aboriginal and Torres Strait Islander Australians and water. The strength of this connection can be seen in various ways. The Gamaraigal people, of what is now known as Sydney, resisted European invaders and objected to them clearing the ground around water holes, casting nets without permission, and interfering in cultural and community practices (Broome, 2002). This strong connection is also evident in how people's behaviours and choices are in part shaped by how communities socially and historically connect to drinking water, perceptions of water quality, and the degree of satisfaction with water management (Doria, 2010; Dupont, Adamowicz, & Krupnick, 2010). The strong connection and the value given to natural sources of water in Aboriginal communities have implications when providing treated drinking water.

Supplying town water to Aboriginal communities without acknowledging and appreciating the unique socioeconomic, cultural, and historical context and values may be futile (Baird et al., 2013; Jaravani, Massey, Judd, Allan, & Allan, 2016). Negative community perceptions and concerns about the safety of supplied drinking water may be a proxy for concerns and experiences of racism and cultural safety (Dupont et al., 2010). There are historical reports of Aboriginal people being killed by poisoned drinking water supplies in the past (Jalata, 2013). These concerns and experiences have reportedly led to higher consumption of substitutes for tap water—such as rainwater, costly bottled water, and soft drinks—in other locations (Deschamps & Prum, 2007), but this set of circumstances has not yet been tested in Australia. For example, in 2006 in the town of Armidale, NSW, bottles of water reportedly cost 400 times the price of town water, which if it were to be used all the time would impact on families' financial resources (Pigram, 2006). The experiences and perceptions of Aboriginal people today towards drinking water are largely unknown.

Walhallow is a small Aboriginal community in northwest NSW that has for many years been concerned with the quality and safety of drinking water. NSW Health has provided bi-weekly monitoring tests of the community water supply (town water) since 2001. The test results indicated that the town water has maintained consistent microbiological quality in accordance with the ADWG (NSW Health, n.d.). In additional, each house is supplied with a rainwater tank and the rainwater supply is pumped to the kitchen sink. The rainwater is not routinely tested.

At Walhallow, the ACWSP program provided an opportunity to implement a risk-based drinking water quality assurance management system. Emergency repair works (such as leak detection and repairs for broken pipe and pumps) and infrastructure works (new bore pump, telemetry, reservoir rehabilitation, and new pressure booster pumps) on the town water supply system have been implemented at a cost of about AUD$238,000 (Bala Thangamany, personal communication). The local public health unit regularly engages with the community and participates with Department of Primary Industries Water (DPI Water) and local government in inspections every 4 months and reviews of the program.

The Problem

From December 2007 to February 2008, the NSW Department of Commerce undertook a survey of the water supply and sewerage services in selected Aboriginal communities including Walhallow (Australian Indigenous HealthInfoNet, n.d.). The survey assessed the existing water and sewage infrastructure, operational procedures, and current levels of servicing and maintenance. The survey found that:

- 10 communities had satisfactory water supply and sewerage services, but required assistance with ongoing management and servicing;
- 31 communities had adequate infrastructure, but needed maintenance and repairs to equipment; and
- 20 communities had inadequate infrastructure and required additional funding (Australian Indigenous HealthInfoNet, n.d.).

In response, the NSW government and NSW Aboriginal Land Council committed AUD$200 million over 25 years, beginning in 2008, to fund the ACWSP to improve the health of Aboriginal communities and help "close the gap" (NSW Department of Water and Energy, 2008).

Observations and informal discussions with the Walhallow community indicated that, despite the investment towards town water that is treated and routinely tested, many community members preferred rainwater. Although they are part of the housing infrastructure, rainwater tanks are not eligible for funding under the ACWSP. The Walhallow Local Aboriginal Land Council (WLALC) is responsible for maintaining the integrity of the houses. It is not clear, however, who is responsible for maintaining rainwater tanks.

We hypothesised that the Walhallow community's drinking water choices were culturally guided by their perceptions of health risk. The study was therefore guided by the following questions:

a. What are the drinking water needs that impact the choice of water source among the Walhallow Aboriginal community?

b. What are the drinking water quality characteristics and differences between rainwater and town water that affect the drinking water choices?

c. Is there a need for change in drinking water policy to include an understanding of community perceptions?

Water supply authorities may have the technology and capacity to supply safe water; however, the acceptability of the town water may not solely be dependent on safety considerations. There may be other factors that need to be identified and understood. Consumers can reveal dominant perceptions and concerns that policy makers need to be informed about to enable effective supply and management decisions (Doria, 2010).

The objective of this study was to explore the experiences of people in the Walhallow Aboriginal community with drinking water, to gain a shared understanding with the community about their concerns about using reticulated water supplies, and then to develop together ways to address these concerns.

Location and History

The study was conducted at Walhallow, which is located at 31°18′S 150°30′E near Caroona in the North West Slopes area of NSW. The community was formally established in the 1870s, although the Gomeroi (Kamilaroi) people lived in this area for thousands of years (Taylor, 1999). Walhallow currently has approximately 100 residents, the Kamilaroi or Gomeroi People, and is estimated to peak at 150 residents during special occasions. Walhallow now consists of 42 brick and tile houses, although in the past people lived in mission-built timber and fibrous cement houses. Since 1998, the village has been served by maintained roads and upgraded water and sewerage systems.

It is generally reported that the Walhallow community did not actively choose their current geographical location and issues of water quality emerged when the community was first displaced and resettled at the reserve. Similar issues have been reported for Indigenous communities in Canada (White, Murphy, & Spence, 2012), USA (Smith, 2005), and New Zealand (Bailie, Carson & McDonald, 2004).

Rainwater storage was connected to the Walhallow community houses when the houses were built in the 1940s (Taylor, 1999). Each house has a 9,000L rainwater tank without filters to strain pollutants, and there is no programmed maintenance of the tanks. Neither the community nor NSW

Health has any record of rainwater tanks being cleaned or the rainwater tank water being tested for microbial contaminants. The quality of the rainwater is unknown and may be unsafe to drink.

The provision of reticulated[1] town water resulted from a needs assessment survey by the community Aboriginal health education officer in 1998 (Taylor, 1999). The assessment fulfilled the recommendation of the race discrimination commissioner investigation into the provision of water and sanitation to Aboriginal and Torres Strait Islander communities. The commissioner recommended a review of the state of water and sanitation in Aboriginal communities (Race Discrimination Commissioner, 1994). Town water was eventually sourced from a bore located about 3 km from the village in an intensive crop agricultural area.

Method

A mixed method design within a community-based participatory action research (PAR) framework was used. The methods included interviews, focus groups, rating of water quality, and water testing. A key strength of a PAR approach is that participants and researchers work collaboratively bringing together their respective knowledge of real world issues and scientific expertise (Cargo & Mercer, 2008). This research design is recognised as culturally acceptable and has allowed us to build sustainable trust with the community (Massey et al., 2012; Weiner & McDonald, 2013).

The initial point for engagement with the community was the existing relationships between the community and the local public health practitioners through several programmes: immunisation programmes; Housing for Health; the ACWSP; and the Companion Animals Health programme. The chief executive officer of the local land council and two other members of the community participated as co-researchers.

Individual Interviews

We used individual face-to-face semi-structured interviews to explore participants' lived experiences and perceptions about town and rainwater through criterion sampling (Creswell, 2013). Some of the participants preferred to gather as a group. Group participation was allowed provided that the participants responded individually. Only participants who were at least 18 years of age and living within the community on a permanent basis were asked to volunteer to ensure independent consent. The age limit ensured independent consent and permanency ensured lived experiences with drinking water in the community.

Participants were asked some specific open-ended questions to express perceptions about water and closed-ended questions to give answers about water quality issues (Baird et al., 2013). Participants were allowed to explain their responses to closed-ended questions. The conversations were voice recorded and professionally transcribed verbatim. The transcripts were then thematically analysed by applying line-by-line coding using a deductive approach to interpret participants' quoted experience as qualitative evidence (Kingston, Judd, & Gray, 2014). Descriptive codes were then entered into a Microsoft Excel 2010 spreadsheet and grouped. Similar codes were consecutively

[1] In Australia, reticulated town water supply means a disinfected drinking water supply system delivered to a town (or community) through a network of pumps, pipes, and water storages (water grid) designed to store and distribute water (Local Government & Municipal Knowledge Base, n.d.).

refined into analytical themes (Pfadenhauer & Rehfuess, 2015). Co-researchers participated fully in the analysis and interpretation of the findings.

Focus Group

We selected a purposive sample of three Elders who grew up in the community, although they had since relocated to the nearby city of Tamworth. These three Elders, who had a longstanding experience with the community, were chosen to inform our understanding of the drinking water history in Walhallow (Creswell, 2013). The Aboriginal co-researchers had significant input into the selection of the focus group members, as well as analysing and presenting the findings as part of the PAR process. The semi-structured interviews guide guided the questions and participants consented to voice recorded dialogue. We thematically analysed the transcripts to merge with the themes from the individual interviews.

Participant-Rated Water Quality

The participants were concurrently asked closed-ended questions to rank both town water and rainwater quality, in regards to the following characteristics: taste, smell, hardness, appearance, pressure, reliability, safety, and maintenance (Appendix 1). Group participants ranked these individually on a 7-point Likert scale. The ranks were then collapsed into two categories: ranks 1 to 4 were categorized as *Good*, and ranks 5 to 7 were categorized as *Bad*. The categories were compared between town water and rainwater using Microsoft Excel.

We used the Satterthwaite approximation method assuming unequal variances and standard deviations between the two water sources because it was ideal for the small sample size (degrees of freedom; Ruxton, 2006). The rating of rainwater to town water was then compared using 95% confidence intervals of the standard deviation and the p-value. When the confidence intervals did not intercept and the p-value was ≤ 0.05 the difference was considered as statistically significant.

Water Testing

Five rainwater tanks were randomly sampled in the community and tested for *E. coli* and total coliforms in accordance with the NSW *Guide for Submitting Water Samples to the Division of Analytical Laboratories for Analysis* (Division of Analytical Laboratories [DAL], 2010). One water sample per tank was collected from the kitchen tap per week for 12 weeks. One house was randomly chosen among the five sample houses for concurrent town water microbiological testing. Town water quality would be expected to be of a constant quality because it is disinfected and is tested fortnightly by the local government. One point of testing only was considered acceptable as a quality control measure. In total, 58 rainwater samples and 12 town water samples were tested for *E. coli* and total coliforms.

Ethics

The Walhallow Aboriginal Corporation as the Local Aboriginal Community Controlled Health Organisation approved the project. Ethics approval was also obtained from the Hunter New England Health Research Ethics Committee (13/10/16/5.06), NSW Health Research Ethics Committee (LNR/13/HNE/418), NSW Aboriginal Health and Medical Research Council's Human Research Ethics Committee (984/13), and James Cook University Human Research Committee (H5531).

Results and Findings

Overall, participants preferred rainwater to town water. Reasons provided by the participants included that rainwater "is more consumable, it is better quality water" and town water is "a bloody big pile of calcium." The main factors that influenced participants' preferences were parental influence, water hardness, and water maintenance. Some participants preferred bottled water to rainwater or town water. Five major themes emerged from the questionnaires about participants' perceptions of drinking water supplies in the community.

Individual Interviews and Focus Group

Fourteen community members, six males and eight females, participated in the individual interviews and responded to all questions. All were above 40 years old and had been residents of Walhallow for many years. The sample size was based on the homogenous makeup of the community and previous qualitative studies that suggested saturation is often reached after 12 interviews (Guest, Bunce, & Johnson, 2006). It has been found that for harmonised communities, like Walhallow, 94% of high frequency codes were identified within the first 6 interviews and 97% within the first 12 interviews (Guest et al., 2006). Francis et al. (2009) similarly found data saturation using retrospective analysis of 10 and 3 additional interviews. Morris (2015) recommends fewer interviews for homogeneous communities and more for studies involving different communities as long as the researchers are satisfied that they have reached saturation.

Five themes emerged from the thematic analysis:

a. Always brought up on rainwater;

b. Rainwater is good . . . but;

c. Town water is good . . . but;

d. If it's maintained then it would be safe; and

e. We buy bottled water.

Always Brought Up on Rainwater

Participants often described how as children they were "always brought up on rainwater" and how "it's been the same for generations." People's knowledge of the source of drinking water has built trust in the rainwater: "Just for drinking, probably rainwater because at least I know where it is coming from." However, another participant noted, "well I think that the rainwater is unsafe, but I think the town water is more unsafe." However, this participant also went on to say, "I think the rainwater would be full of bugs and gunk."

The Elders focus group explained how "it was just drilled in to me that you don't touch the hard water" and "you drink rain water, don't drink that hard water, don't know why, probably a cultural thing." Participants often explained that "it's been the same for generations," but "you never got an explanation why, not to drink it." They explained, "You would get in trouble from your parents, they use to tell us don't drink town water, drink the rainwater."

One Elder in the group further explained why rainwater was preferred to town water:

> As far as the tank water is concerned the people always chose tank water because it was soft water and the result of using tank water as opposed to town water was people could see it in their tea, with the taste of tea and the hardness of the tea and that sort of thing. You could see it straight away, so it was something that was always in front of you every dinnertime, so tank water was always considered the best because it didn't do that.

Rainwater Is Good . . . But . . .

Participants frequently described the taste of rainwater as: "very good . . . will be [ranked] one out of seven for rainwater [one being best]"; "tastes better"; "it is more consumable"; "it is better quality water"; "because it is softer, it is clearer"; "it hasn't got any smell"; and "tastes fresher." Participants also described how they felt safe with drinking rainwater: "I've been drinking it [rainwater], and it hasn't made me run to the toilet or anything."

However, several participants disliked rainwater because it is: "shocking, very, very poor"; "when you run the tap it is yellow or brown"; and "it is not as good as it used to be, so it is terrible now, it is not as good as it was when we were growing up either." Some participants said, "Mine is nice to drink and that, like I still drink it but I really think that it is contaminated, like frogs and whatever else is in there. Plants, like I've got plants growing out of my tank." "There has always been *E. coli* in water out here," and "It used to give me UTIs [urinary tract infections] constantly."

Town Water Is Good . . . But . . .

Participants frequently described town water as "pretty good and clear"; "looks alright"; "it is drinkable";" better than my rainwater"; "it doesn't smell"; "is 100 times better in terms of smell than those [other] places"; and "I don't mind the taste either." Participants generally liked town water: "Because you use it more. Like everyone uses it more than their rainwater." And if there are no "rains you have got no water anyway so you have got to have some sort of supply, so I reckon the town water. And health wise and all that stuff."

However, participants often referred to town water as the "hard water." Participants asserted that town water caused skin problems such as "itchy and scaly skin" and "very harsh on the skin and you can tell with the shower how it builds up with the calcium." One participant remarked, "You look at the showers and that, what do you think they do to our insides too?" Many participants talked at length about "calcium build-up in the water heaters," and the need to regularly "dig it all out."

Participants also complained about the cost of maintaining hot water systems because of the hardness of the town water. For example, as one participant articulated"

> He [the plumber] is probably out here; probably about, I don't know, 6 times a year doing it. The elements have got like salt; I have got to get the elements replaced all the time. I have had I think it is two hot water systems . . . in nine years.

If It's Maintained Then It Would Be Safe

Participants said that if the rainwater were properly maintained "then it would be safe." Several participants were aware that town water was being maintained: "They come out every couple of months because you see them. I know, I see them coming out all the time."

Several participants wanted the local government to extend their services to rainwater. For example, one participant said, "It goes in with the general maintenance of it, that program of the councils where they are coming out and checking, that should be extended to the tank system." Another said, "It would be good to have the tanks cleaned out probably get some new water in it." One participant countered that "whoever has got the houses have a responsibility . . . they have to be kept to it."

Lack of information was frequently cited as contributing to residents' rejection of town water. An Elder resident was dismayed: "Ahh, yuck! We don't know what we are drinking." Several participants did not even know "if it is bore water or bloody river water" or "whether it is coming from some unknown source . . . probably from the river." A participant then wanted to know the effects of chlorine: "Chlorine! What will chlorine do to you though? It is a chemical isn't it?"

We Buy Bottled Water

Participants who dislike both rainwater and town water often said, "We buy bottled water" because "you can just tell that bottled water has been filtered because it feels more natural . . ." and "it is supposed to be the best or something."

However, one Elder participant said he "won't buy water. It is too dear." Community members who cannot afford the cost often get bottled water from the local pre-school. The pre-school was said to "always have heaps of water, cold in the fridge and especially in summer time they are all like can we have bottles of water."

Participant-Rated Water Quality

The rating of water quality characteristics helped us to identify which water attributes participants believe are most important in determining the drinkability of each type of water. The ordinal data was collapsed into two categories of *Good* or *Bad* to capture the participants' perceptions of the water. If the participant rated the water characteristic favourably (1-4), their perception for that characteristic would be good. Otherwise, it would be bad, which may ultimately lead to the rejection of the water.

Participants generally rated rainwater taste and hardness as most important in deciding their preferred drinking water source (Table 1). Town water taste was rated *Very Bad* (0 rating it as *Good* and 14 rating it as *Bad*) compared to 9 *Good* and 5 *Bad* for rainwater, which is statistically significant ($t(17.26) = -3.42$, $p = 0.003$). Town water hardness was rated as *Very Bad* (0 rating it as *Good* and 14 rating it as *Bad*) compared to rainwater (14 rating it as *Good* and 0 rating it as *Bad*), which is statistically significant ($t(16.81) = -6.12$, $p = 0.0001$).

Secondly, the participant ratings helped us to compare the water attribute rated as most in need of urgent improvement for each type of water (Table 2). Town water hardness was the higher priority (14 rating it as a *High Priority* and 0 as a *Low Priority*) compared to rainwater (0 rating is as a *High Priority* and 14 rating it as a *Low Priority*) and statistically significant ($t(18.96) = 6.94$, $p = 0.0001$).

Table 1. Participant Rated Water Quality Attributes by Water Source, Walhallow, March 2014

Water Characteristic	Water Source	*Good* *n*	*Bad* *n*	*t* (*df*)	95% CI of *SD*	*p*
Taste	Town	0	14	-3.42 (17.26)	[0.68, 5.31]	0.003**
	Rain	9	5		[1.68, 2.24]	
Smell	Town	10	4	-0.79 (25.57)	[1.29, 2.40]	0.437
	Rain	11	3		[1.48, 1.68]	
Appearance	Town	12	2	0.75 (22.88)	[1.70, 2.15]	0.458
	Rain	10	4		[1.15, 2.01]	
Pressure	Town	14	0	0.85 (22.87)	[0.90, 1.28]	0.406
	Rain	11	3		[1.33, 1.44]	
Reliability	Town	9	5	0.43 (25.94)	[1.62, 2.42]	0.668
	Rain	5	9		[1.54, 2.84]	
Safety	Town	8	6	0.65 (25.12)	[1.34, 2.72]	0.524
	Rain	6	8		[1.62, 2.99]	
Hardness	Town	0	14	-6.12 (16.81)	[0, 0.62]	0.0001***
	Rain	14	0		[1.44, 1.59]	

Note. Participants rated each characteristic on a 7-point Likert scale with 1 being the *best* and 7 being the *worst*. The results are displayed as two categories: *Good* (1-4) and *Bad* (5-7). In order to assess whether differences in the ratings of town water and rainwater were statistically significant, the Satterthwaite unequal variance t-test was performed on the ordinal level data for each characteristic. CI = confidence interval. *SD* = standard deviation. $N = 14$.
* $p < .05$. ** $p < .01$. *** $p < .001$.

Table 2. Participant Rated Water Attribute Most in Need of Improvement by Water Source, Walhallow, March 2014

Water Characteristic	Water Source	High Priority *n*	Low Priority *n*	*N*	*t (df)*	95% CI of *SD*	*p*
Taste	Town	10	2	12	-1.09 (25.99)	[1.37, 2.70]	0.285
	Rain	8	4	12		[1.39, 1.89]	
Smell	Town	5	6	11	-1.24 (23.25)	[1.32, 3.19]	0.223
	Rain	9	3	12		[1.09, 2.63]	
Appearance	Town	1	10	11	-1.97 (24.95)	[1.22, 4.28]	0.061
	Rain	6	6	12		[1.27, 2.99]	
Pressure	Town	3	8	11	-0.69 (20.00)	[1.82, 3.39]	0.113
	Rain	5	7	12		[1.15, 3.43]	
Reliability	Town	3	8	11	0.81 (25.82)	[1.62, 4.02]	0.423
	Rain	3	9	12		[1.76, 3.33]	
Safety	Town	8	3	11	-0.11 (24.67)	[1.51, 2.11]	0.913
	Rain	8	4	12		[1.81, 1.85]	
Hardness	Town	10	2	12	6.94 (18.96)	[0.69, 1.55]	0.0001***
	Rain	1	12	12		[1.01, 6.4]	

Note. Participants rated each characteristic on a 7-point Likert scale with 1 being the *highest priority* and 7 being the *lowest priority*. The results are displayed as two categories: *High Priority* (1-4) and *Low Priority* (5-7). In order to assess whether differences in the ratings of town water and rainwater were statistically significant, the Satterthwaite unequal variance t-test was performed on the ordinal level data for each characteristic. CI = confidence interval. *SD* = standard deviation.

* $p < .05$. ** $p < .01$. *** $p < .001$.

Water Testing

Rainwater tests at Walhallow indicated that half of the rainwater tested had *E. coli*. Of the samples tested, 30/58 (52 %) had *E. coli* with a mean of 18 colony-forming units per sample (Table 3). Overall, 3/5 rainwater tanks had more than 50% *E. coli* detection rate[2] over the sampling period. The ADWG recommends no *E. coli* in every 100ml of a drinking water sample. There is no guideline value for total coliforms as they are not recommended for use as an indicator of faecal contamination. Total coliforms are an indicator of disinfection efficiency. Rainwater at Walhallow is not disinfected.

Discussion

Parental influence, town water hardness, and rainwater maintenance were the main factors influencing participants' choice of drinking water. Participants rated town water hardness significantly different from rainwater. The difference between the other water characteristics was not statistically significant. About half of rainwater samples had *E. coli* while town water samples did not detect any *E. coli*. Participants also suggested that if rainwater were properly maintained then it would be safer.

Early engagement and social interactions developed trusting relationships, fostered cultural appropriateness, and provided opportunities to learn community protocols, and to use appropriate language and avoid sensitive behaviours. The active participation of community members as co-researchers developed legitimacy and goodwill with the community.

Parental Influence

The significance of interpersonal relationships, parental influence, and community culture was a strong and recurring message from participants although water safety, smell, and taste were also discussed often. Consequently, the rejection of treated town water in favour of untreated rainwater at Walhallow has been passed on from generation to generation, placing the community, particularly children, at risk of waterborne enteric diseases through consuming possibly unsafe rainwater.

Influence, or habit, that is passed from generation to generation becomes a tradition and consequently a culture. Culture is defined as the shared patterns of behaviours and interactions, cognitive constructs, and affective understanding that are learned through a process of socialization (Centre for Advanced Research on Language Acquisition [CARLA], n.d.). Aboriginal culture and kinship are strong and act as protective forces for children and families (Secretariat of National Aboriginal and Islander Child Care [SNAICC] & Innovative Resources, 2009). A participant described how hard it is to get out of a habit instilled by one's parents: "I was always brought up, like it is hard to get out of your [habit], when you are used to rainwater."

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[2] The *E. coli* detection rate is the number of *E. coli* detections divided by the number of samples multiplied by 100 to create a percentage (i.e., the proportion of samples with *E. coli* to the total number of samples tested per house).

Table 3. Rainwater and Town Water Testing Results, Walhallow, November 2014 to January 2015

House Number	Water Source	Number of Samples	*E. Coli* Detections	Total Coliforms Detections
1	Rain	12	9	10
2	Rain	12	9	11
3	Rain	10	4	7
4	Rain	12	7	11
5	Rain	12	1	8
2	Town	12	0	1

Cultural influence is not unique to the Walhallow community. Culture and law are used interchangeably among Aboriginal and Torres Strait Islander Australians, illustrating that community connections, activities, and knowledge govern people's behaviour (Barber & Jackson, 2011). Throughout Australia, Aboriginal peoples have a strong association with country, culture, kinship, and self-determination; these are characteristics that have been reported to safeguard communities against transgenerational trauma (Australian Indigenous HealthInfoNet 2016; Colquhoun & Dockery, 2012).

Parental influence over drinking water has also been demonstrated in rural Kenya (Makutsa et al., 2001) and India (Firth et al., 2010), where low cost drinking water contamination interventions were hindered by cultural practices that caused low acceptance and sustained the use of untreated water. In Camarines Sur, Philippines, in 2012, it was found that villagers who had access to chlorinated water chose to drink from untreated wells because parents were resistant to change, despite deaths due to a cholera outbreak (De Guzman, Carr de los Reyes, Sucaldito, & Tayag, 2015). Drinking water suppliers should therefore be aware of parental influences on water choices and be prepared to address public health problems associated with drinking water in a social context in addition to scientific knowledge (Gorelick et al., 2011).

Rainwater Safety

The participants' perceptions were that the taste and smell of rainwater were good. Other studies (see for example Wright, Yang, Rivett, & Gundry, 2012) have highlighted the importance of taste and smell in determining people's choices in drinking water. In the current study, although participants knew that rainwater's microbiological quality was poorer than town water, they still preferred rainwater. A participant who had her rainwater tested and found it to be contaminated did "a bit of research . . . and stopped drinking it." Instead of switching to town water, she preferred to "go to the old girls [house over the road] and use their [rain] water." While the drinking of rainwater is not unique to Walhallow, NSW Health does not endorse this practice when reticulated town water is available (NSW Health, 2007; enHealth 2010). According to NSW Health (2007), where treated water is provided, rainwater may be used for low risk uses such as hot water services, laundry, toilet flushing, or gardening. In 2013, the Australian Bureau of Statistics (ABS) reported that 19.3% of rural NSW households had rainwater as the main source of drinking water compared to 76% for rural South Australia and 23% of other rural Australian households (ABS, 2013).

Frequent detection of *E. coli* in the rainwater test results is not surprising, given that roof catchments and guttering are subject to contamination by bird and small animal droppings, which are known to harbour potential pathogens. A study in South Australia found that 59% of rainwater tanks in Aboriginal communities had either faecal coliforms or Streptococci (Plazinska, 2003). Other studies of rainwater tanks in southeast Queensland detected *Salmonella, Giardia lamblia, Legionella pneumophila, Campylobacter jejuni*, and *Cryptosporidium parvum* (Ahmed, Hodgers, Sidhu, & Toze, 2012; Ahmed, Vieritz, Goonetilleke, & Gardner, 2010), which were tracked back to possum and bird faecal samples.

The presence of faecal coliforms such as *E. coli* in rainwater does not necessarily mean that the community will get ill from drinking the water. There are no records of waterborne disease outbreaks at Walhallow, although sporadic and unreported cases cannot be discounted. Continuous contact with a risk often results in the normalisation of the risk, where the individuals become familiar and desensitised to its presence (Halpern-Fisher et al., 2001).

Epidemiological investigations undertaken in South Australia have failed to identify links between rainwater tanks and gastrointestinal illness despite global underreporting contributing to a lack of evidence (Heyworth, 2001; Heyworth, Glonek, & Maynard, 1999; Rodrigo, Sinclair, Forbes, Cunliffe, & Leder, 2010). A study by Heyworth, Glonek, Maynard, Baghurst & Finlay-Jones (2006) found that there was no difference in the incidence of gastroenteritis in children who drank rainwater and those who drank treated town water. In our study, participants who drank rainwater often said they have not had diarrhoea or other symptoms from the water; hence, they assumed that it was safe for drinking: "I don't have any issues with it." "It [*E. coli*] has always been mainly in the drinking water, they did surveys ages ago, with *E. coli* in them. I reckon because the insects and frogs get in the rainwater."

Town Water Hardness

During the period 2006 to 2015, routine town water monitoring data for Walhallow showed that the mean total hardness measured as calcium carbonate ($CaCO_3$) was 268 mg/L compared to the ADWG value of 200 mg/L (NSW Health, n.d.). Participants often referred to town water as "hard water" that caused "itchy and scaly" skin after bathing. Consequently, the community disliked the town water and this may lead to perceived water insecurity. When hard water is heated, the calcium hydrogen carbonate ($Ca(HCO_3)_2$ that causes the hardness is converted into $CaCO_3$, which is deposited as a whitish scale. Hence "hard water" is the qualitative description that people use for the scaling actions of water, while water hardness is a quantitative measure of metal ions that are dissolved in the water usually measured as CaCO3 (McMellon, 2010).

Hard water scale accumulation causes the elements of hot water systems, kettles, and appliances to overheat and burn out, resulting in higher energy bills that become a burden on low-income Indigenous families (Browett, Pearce, & Willis, 2012). Hard water also causes malfunctioning of health hardware by clogging internal plumbing and water appliances, increasing the frequency of fixture repair and maintenance costs. For example, replacing a solar hot water system in Central Australia costs AUD$5,000 and the replacement of tapware cost AUD$100 per tap (Browett et al., 2012; Downing, 2000). Additionally, households must purchase large volumes of expensive soaps, softeners, and other cleaning materials that are capable of lathering in hard water (Pearce, Willis, McCarthy, Ryan, & Wadham, 2008). Therefore, water related expenses may be undertaken at the expense of other pressing household issues.

Water hardness is not unique to Walhallow. Even mainstream towns around Walhallow such as Quirindi, Gunnedah, Narrabri, and Moree that use similar groundwater do not treat for water hardness due to the prohibitive cost. However, larger regional towns and cities can soften their water supply by treating it to remove calcium and magnesium. However, any potential public health risks would depend on the local concentration of minerals, other than those contributing to hardness, in the respective aquifer (NHMRC & NRMMC, 2011).

Water Quality Maintenance

Participants indicated that if the water sources were properly maintained then the water would be safer. Considering the health risks of drinking untreated rainwater instead of treated and routinely tested town water, responsibility for drinking water safety at Walhallow requires interagency negotiation for improvements at the service level. The regional public health unit could help with educating the community on the advantages of choosing town water over rainwater to promote the use of safer town water. Community members who choose to continue drinking rainwater would need to boil the water before drinking it.

Bartram (1996) suggested that a drinking water service level is conditioned by continuity and quality (safety), such that service quality = service level × continuity × safety (see also Kayser, Moriarty, Fonseca, & Bartram, 2013). Although town water continuity and service level are guaranteed at Walhallow, safety is diminished because people do not drink it due to its hardness. Thus, the service quality is compromised by a diminished perception of safety. Reduced service quality undermines the value of the service and associated public health benefits. In Canada, for instance, it was found that the degree of concern about the health risk of town water was inversely proportional to town water consumption and to aesthetic concerns raising the consumption of bottled water (Dupont et al., 2010).

The World Health Organization (WHO, 2011) *Guidelines for Drinking-Water Quality* define domestic water as water used for all usual domestic purposes including consumption, bathing, and food preparation. To promote health, an individual needs a basic water supply of 20L per day for of which only 2 litres (10%) is for direct consumption (drinking and food preparation). However, considering that the Walhallow community is provided with an optimal service water supply (100L/day; Howard & Bartram, 2003) direct consumption is only 2%. The bulk of the service (98%) goes to other health or household needs such as food preparation, bathing, and laundry. Therefore, treating the safe town water for hardness would be essential for general health promotion in the community.

The introduction of the NSW Aboriginal Communities Water and Sewerage Program has created interdepartmental alignment in the provision of safe drinking water to Walhallow and other NSW Aboriginal communities. The WLALC, NSW Office of Water, Hunter New England Population Health Unit, and local government all work across disciplines to deliver safe town water to Walhallow.

The NSW *Guideline on Rainwater Tanks Where a Public Water Supply is Available—Use of* (NSW Health, 2007) spells out the best methods for maintaining rainwater tanks. These include tank design and maintenance, catchment management, tank desludging, and maintenance. Rainwater quality can be improved by the use of first flush devices and filters that are properly maintained and meet an appropriate standard such as AS/NZS 4348 or ANSI/NSF 53 (NSW Health, 2007). Properly maintained rainwater tanks can "provide good quality drinking water. Rainwater tanks are widely used as a source of drinking water throughout rural Australia. Occasionally there are cases of illness from contaminated rainwater" (NSW Health, 2007, p. i). People who decide to use rainwater for potable uses should be aware of potential risks associated with microbiological and chemical contamination. The WLALC may have to consult again with the community about who is responsible for and how rainwater maintenance occurs.

Buying Bottled Water

The preference for bottled water among some of the participants was due to perceived safety and aesthetic considerations of the current supplies. One participant said, "[Bottled water is] supposed to be the best." Low perceptions of town water have been associated with higher consumption of costly bottled water and sugary beverages, resulting in high incidence of related diseases such as diabetes, gastritis, and obesity in Indigenous communities elsewhere (see for example Sarkar, Hanrahan, & Hudson, 2015). Water insecurity and poverty also caused a high intake of sugary beverages in Canada's Inuit Indigenous community resulting in high levels of related diseases such as diabetes and obesity (Sarkar et al., 2015). Where water supplies are fluoridated, drinking bottled water may also reduce the fluoride intake among children leading to poorer oral health (Gorelick et al., 2011).

Generally, Australians choose bottled water because of concerns about microbiological quality of town water, avoidance of chlorine, preferred taste, and the perception that bottled water is healthier (Cochrane, Saranathan, Morgan, & Dashper, 2006). Studies in the United States (Gorelick et al., 2011) and rural Canada (McLeod, Bharadwaj, & Waldner, 2014) found health risks and aesthetic complaints about town water to be the most frequently cited factors influencing the consumption of bottled water. However, studies in England (Ward et al., 2009) and Portugal (Doria, 2006) found that taste was the most important consideration in choosing bottled water.

Policy Implications

The diseconomies of scale experienced by small Aboriginal communities present difficulties for policy makers. The cost of financing water supply treatment, especially to treat water hardness, can be exorbitant on a per service basis. The current policy regime may not be sufficiently flexible to deal with the diversity of consumer preferences and different cost-benefit trade-offs between communities. However, it is difficult to precisely identify and measure the health effects of improved water supply. Governments, water suppliers, and consumers would need to make practical decisions on the most rational solutions and compromises. This decision-making requires a balanced consideration of the health risks, the cost of treatment, and community aspirations for enhanced water quality.

Water hardness, taste, and smell are primary determinants of aesthetic acceptability of drinking water at Walhallow, and indeed other communities, but cannot be disassociated from health considerations. Community acceptance of a water supply is determined by cultural conditioning, perceptions of safety, and level of consumer education on water safety among other issues (Doria, 2010). It is not adequate to conclude, on the basis of technical comparison of physical characteristics of water among communities, that consumers will obtain equal benefits from the introduction of the same level of service (Race Discrimination Commissioner & Australia, 1994). It is important to promote equality as a measure of outcomes of actions, instead of the input of similar resources in different situations (Race Discrimination Commissioner, 1994).

There is no specified rainwater strategy for the Walhallow community and there are no technical standards that apply to rainwater because it does not form part of the authorised supply system. Rainwater tanks are the property of the housing provider. The role of the housing provider or occupier in maintaining the tanks is not clear. The ACWSP only extends to the housing block boundary. Should the ACWSP be extended to include the houses? Would the funds be adequate? What are the policy implications in other communities? Furthermore, would the community be able to afford the higher water rates due to water softening? These are some of the policy issues that need further discussion and consideration.

The ACWSP is currently undergoing a planned review. In response to this study, the feasibility of installing a water softener at Walhallow is under consideration. The WLALC is also considering the feasibility of regular rainwater tank maintenance. We contend that if the town water is softened, the community is adequately consulted and educated, and children are allowed to choose with time there may be generational change and the uptake of safer town water will increase.

Strengths and Limitations

A major strength of this study is that a PAR approach allows a high degree of community involvement and empowerment, which resulted in the findings being context appropriate. PAR methodology is a culturally appropriate approach for working with Aboriginal communities for a joint research outcome and can be applied in and with other Aboriginal communities in NSW and Australia. The community co-researchers gained valuable skills in research methods and water testing. The researchers and the community are working together to improve rainwater maintenance and to advocate for ways to soften the town water to meet the ADWG 2011 value, for the benefit the community.

The sample size has made the effects of gender and age on water preferences difficult to interpret. The study was carried out in a particular context and a particular community, we are therefore unable to generalise these results to all Aboriginal communities in NSW or Australia. However, this study may give some good foundations for further studies in other communities. Every Aboriginal community has unique physical, cultural, economic, and social environments, which may cause communities to have different attitudes towards their drinking water supplies (Anadu & Harding, 2000; Hu, Morton, & Mahler, 2011). The timing of the water testing also made it hard to predict the impacts of seasonality and drought.

Our study was unable to relate health outcomes to water quality data and identified preferences; further research is required to address this data gap. A major research priority is the assessment of the uptake and acceptance of town water supplies in multiple rural NSW Aboriginal communities. A cost-benefit study could develop better understandings about whether the resources expended in maintaining the town water supplies are worthwhile and cost effective. This may also contribute to the improvement of the quality of the community-preferred sources.

Conclusion

In this study, we found that the perception of town water hardness and parental influence were key factors associated with participants' decisions to drink rainwater. Perceptions of town water and rainwater quality and safety were also associated with decisions by some to drink bottled water. Considering the potential costs of repairing and replacing malfunctioning scaled health hardware, the cost of soap and detergents, the cost of drinking water substitutes like bottled water and fizzy drinks, and the health impacts of untreated rainwater, the need for softer town water is compelling.

This study presents important insights that water supply authorities need to consider when assessing health risks: choosing appropriate mitigation measures and building business cases for water quality improvement programs at Walhallow. The findings can inform potential interventions to improve drinking water quality in Aboriginal communities by involving communities in the process and by addressing community social concerns about town water supplies. Tangible improvements in the quality of town water will not be fully recognised if the community is distrustful about the supply. Understanding this paradigm can improve future programs and policies for the supply of adequate and acceptable drinking water to Aboriginal communities. Programmed interventions are unlikely to fully achieve the intended benefits without a good understanding of the social factors influencing drinking water choices by incorporating appropriate and adequate responses in partnership with communities to mitigate such factors.

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Appendix 1

Interview Questionnaire

My name is . . . from Hunter New England Population Health. I hope you have heard about the community project on drinking water from the previous consultation meetings or from the Local Aboriginal Land Council.

The Walhallow Aboriginal Land Council, on behalf of the community, and the Hunter New England Population Health Unit are currently working together to conduct an assessment of the community's drinking water needs. The results of the assessment will help the community to map the required activities to improve the health of the Walhallow community through drinking water of known quality. The assessment will also provide Hunter New England Population Health with opportunities to learn about what issues about drinking water are most important to Walhallow community and what can be done to address those issues.

As a member of the Walhallow Community over the age of 18 years and living in the community, we would like to know what you think about the quality of drinking water in the community. We are therefore inviting you to participate in this assessment.

It is important that you should know that your participation in this assessment is voluntary. Should you agree to participate, you are free to withdraw at any time. Your name or address will not be recorded. The answers will be recorded in a voice recorder and on the printed questionnaire.

All information collected will be owned by the Walhallow Aboriginal Land Council.

Do you agree to participate?

A. Participant Information

Participant = any community member over 18 years old

Gender- male/ female

Age group

16-18	19-24	25-40	41-50	51-65	65-75	76-85	>85

B. Water Preferences

1. Can you describe what you use rainwater for?
2. Can you explain what you use town water for?
3. How would you describe the rainwater quality?
4. How would you describe the town water?

5. How would you rank the water quality between 1 and 7 with 1 being *the best* and 7 *the worst*?

Water Source	Water Characteristic						
	Taste	Smell	Appearance	Pressure	Reliability	Safety	Hardness
Rainwater							
Town water							

6. Which water characteristic do you consider the most important? Rank between 1 and 7 with 1 being *the best* and 7 *the least*.

Water Source	Water Characteristic						
	Taste	Smell	Appearance	Pressure	Reliability	Safety	Hardness
Rainwater							
Town water							

7. Which water source do you trust most? Why?
8. Which supply do you recommend to your children? Why?
9. Which supply do you recommend to your visitors? Why?
10. If rainwater were to run dry, would you drink town water? Yes/No
11. If your answer is "No," can you explain why?
12. If town water were to run dry, would you drink rainwater? Yes/No
13. If your answer is "No," can you explain why?
14. When you visit town do you drink town water? Yes always/Yes sometimes/Never
15. If never, what do you drink if you become thirsty?
16. Can you explain why you do this?
17. Can you tell me about a time when you went away from Walhallow and what you did about drinking water?
18. When your children go to school, do they carry drinking water with them? Yes/No
19. If your answer is "Yes," which water?
20. Can you explain why the children carry the water to school?

C. Water Management

1. How would you describe drinking water maintenance in Walhallow?

1 = *Very Good*; 2 = *Good*; 3 = *Bad*; 4 = *Very Bad*

Rainwater	
Town water	

2. If any improvements were to be made which issues would you prefer to be addressed first? Rank them 1-7 (1 for the *highest priority* and 7 for *lowest priority*).

Water Source	Water Characteristic						
	Taste	Smell	Appearance	Pressure	Reliability	Safety	Hardness
Rainwater							
Town water							

3. If only one water source were to be improved, which water would you prefer? Why?

4. Who do you think should best be responsible for the water maintenance? Why?

D. Culture

1. Do you use the water for any cultural purposes? Yes/No
2. If yes, which water supply? Town/Rainwater
3. Can you describe what type of cultural purposes?
4. Does the source of the water have any influence on your choice of water? Yes/No
5. Can you describe what the influence is?
6. Does the quality of the water have any influence on the choice of water? Yes/No
7. Can you describe what the influence is?
8. Which water quality criteria do you consider most when using the water for cultural purposes?
9. Can you explain why?

E. History

In relation to the history of Walhallow, from a long time ago to more recently, what are some of the issues that relate to the safety of drinking water?

Do you have any other issues pertaining to drinking water in Walhallow that you would want to be addressed?

Chapter. 6 Water Quality in Recreational Swimming Sites in the Hunter New England Region, New South Wales, Australia

6.1 Overview

Outbreaks of waterborne diseases associated with recreational water contamination are a major public health concern worldwide (Wheeler et al., 2002). Ensuring the safety of recreational waters for public use is a priority of public health authorities, expending considerable resources to monitor water quality at recreational sites (Boehm et al., 2009). Literature indicates that most waterborne gastrointestinal infections in NSW were linked to recreational water than to drinking water (Waldron et al., 2011; McAnulty et al., 1993). Even case-control studies in Australia suggested that contaminated recreational rather than drinking water may be the primary mode of spread of enteric pathogens (Dale et al., 2010; Puech et al., 2001). This chapter discusses potential public health risks posed by fresh and brackish water swimming sites in Hunter New England (HNE), NSW, Australia, and to promote preventive risk management.

Surface water bodies such as dams and rivers are often used for recreational activities such as swimming, kayaking, fishing, and boating. Thus, despite the safety of drinking water, which undergoes treatment to remove microbial risks, consumers may also contract gastrointestinal infections from recreational swimming sites (Plate 6.1). Therefore, discussing the impacts of recreational water quality on environmental health is important to complete the bridging of the gap between practitioner-led investigations and policy on water quality management. It is noted that recreational bathers normally ingest smaller volumes of untreated water, compared to the volumes ingested as treated drinking water (WHO, 2003). Recreational water quality monitoring programmes are a significant resourcing burden, requiring multiple staff and days to carry out weekly surveillance sampling (Milne et al., 2017). This chapter reports on the assessment of the quality of water at seven selected popular fresh water swimming sites in the Hunter New England region of New South Wales to assess their potential public health risks.

Epidemiological studies have shown numerous gastrointestinal, respiratory, eye, ear and skin infections associated with faecally polluted recreational water (WHO 2003). The most commonly recognised risk to human health posed by contact with recreational waters is faecal contamination which can contain a range of pathogenic organisms including bacteria, viruses and protozoa. Many environmentally persistent gastrointestinal pathogens such as the *Cryptosporidium parvum* parasitic protozoa, *, E. coli 057:H7* and *Campylobacter spp bacteria* and various enteric viruses are abundant in recreational waters (NHMRC, 2008; Hambidge, 2001; Li et al., 2002; Robertson et al., 2002). Non-gastrointestinal infections *by Naegleria fowleri, Mycobacterium ulcerans Mycobacterium intracellularem* and *Mycobacterium avium, Pseudomonas aeruginosa, Staphylococcus aureus* bacteria are of significant concern to immuno-suppressed people (WHO, 2003, NHMRC, 2008, Falkinham et al., 2001).

Loganthan et al. (2012) found that recreational water catchments which allowed swimming and camping showed a predominance of *C. hominis* compared to non-recreational catchments, which had a higher prevalence of *C. parvum*. Notification data suggest environmental factors are important predictors of these diseases (Lal et al., 2015). Therefore, it is essential for risk-based water quality management programs to consider such pathogens, which cannot be monitored by measuring the common water quality monitoring indicators like *E. coli*, to protect public health. However, monitoring may be costly relative to the utility of the information gained, aspects of recreational water use as a value besides health should be considered (e.g., aesthetic considerations), and the roles and responsibilities of regional, local and public health authorities require clearer delineation (Milne et al., 2017). Scientifically robust and cost-effective systems to evaluate human health risks, and timely, clear and consistent communication of these risks are required to protect public health.

Sanitary surveys for potential faecal contamination sources and a matrix of the likelihood and consequences of contamination at each site were used to determine a Sanitary Risk Category. Water sampling and testing for enterococci indicator bacteria occurred at these informal swimming sites. The EnteroTester Template V677 was subsequently used to calculate the enterococci count 95th percentile and the Microbial Risk Category for each location. A risk matrix of the Sanitary Risk Categories and the Microbiological Risk Categories was used to determine the Water Quality Grade for each site using the Australian Guidelines for Managing Risks in Recreational Water 2008.

The risk of acquiring gastrointestinal illness from exposure to specific concentrations of faecal indicator organisms is predictable (Havelaar et al., 2001; Kay et al., 2004). Studies have found a correlation between intestinal *Enterococci* contamination and gastrointestinal disease with a yearly attributable risk for fresh-water-associated gastrointestinal illnesses of 1 case/1,000 person-years, for 100 bacteria/100 ml fresh water (Wiedenmann, 2006; Zmirou et al., 2003). Despite this established risk, and the popularity of freshwater recreational sites, monitoring of faecal contamination in these inland waters is uncommon in Australia (Sinclair Knight Merz, 2011).

Plate 6.1 Children swimming in source water: Chaffy Dam, Tamworth, NSW, 2015 (Personal collection)

6.2 Research Impacts

Evaluation of the research significance has not yet been completed. The evidence from the water test results has prompted local improvements in risk management strategies. While the evidence highlights a need for policy change involving water quality monitoring at popular freshwater swimming sites, further negotiation with the respective local governments in the region to explore ways of managing the popular swimming sites is continuing. The local governments have emphasised the need for water quality guidelines for freshwater swimming sites. Codification of these guidelines should improve recreational water quality in northern NSW and state-wide. Advocacy has been initiated for state-wide policy change.

6.3 Journal Publications

6.3.1 Microbiological water quality at recreational swimming sites in regional Hunter New England, New South Wales, Australia

The findings from this research and the policy implications are under peer-review for publication:

Citation: **Jaravani, F. G.**, Porigneaux, P., Main, K., Butler, M., Durrheim, D. N., Byleveld, P., Judd, J., & Oelgemoeller, M. (Under review). Microbiological water quality at recreational swimming sites in regional Hunter New England, New South Wales, Australia. *Australasian Journal of Environmental Management,* TJEM-2018-0069.

Water quality in recreational swimming sites in Hunter New England region, New South Wales, Australia

Abstract

The microbiological quality of many popular fresh or brackish water recreational swimming sites in rural Hunter New England, New South Wales, Australia is generally unknown. This study assessed the microbiological water quality of popular recreational swimming sites to provide empirical evidence of potential public health risk and to promote preventive risk management. Sanitary inspections for potential faecal contamination sources and matrices of the likelihood and the consequences of contamination at each site were used to determine the Sanitary Inspection Category. Water sampling for enterococci indicator bacteria and the EnteroTester Template V677 were used to determine the Microbiological Assessment Category for each site. The Sanitary Inspection Category and Microbiological Assessment Category matrix then used to determine the Water Quality Grade classification for each site. All sites exceeded the National Health and Medical Research (NHMRC) enterococci illness transmission level of 40 colony forming units/100 mL. The Water Quality Grade for six out of seven sites indicated poor microbiological water quality. The high enterococci densities found suggest that other microorganisms, like virus and parasites, may also be present, representing an immense public health risk concern. Further research to understand the microbial communities and their health effects will improve site management options.

Keywords: microbiological assessment category; microbiological water quality; recreational swimming sites; recreational water quality; sanitary inspection category; water quality grade

Introduction

Recreational use of water can deliver important benefits to health and well-being (Yihdego 2016; NHMRC 2008). Microbiological contamination of recreational waters by faecal waste and enteric pathogens is a major global concern (Wheeler et al., 2002). The risk of acquiring gastrointestinal illness associated with exposure to recreational water containing certain concentrations of faecal indicator organisms is predictable (Havelaar et al., 2001; Kay et al., 2004) through primary contact activities like swimming, surfing and water skiing or secondary contact activities with limited risk of water swallowing such as boating, fishing, paddling and wading (WHO, 2003; Yihdego, 2016).

Accidental water ingestion during water contact recreational activities resulting in gastrointestinal illness is common (Dufour et al., 2006). Children are reported to swallow about twice the amount of water swallowed by adults (Dufour et al., 2006; Schets, Schejven and de Roda Husman, 2011). Studies have found a correlation between intestinal enterococci in recreational water and gastrointestinal disease (Havelaar et al., 2001; Kay et al., 2004). The yearly attributable risk for fresh-water-associated gastrointestinal illnesses is 1 case/1,000 person-years for 100 enterococci /100 mL fresh water (Zmirou et al., 2003). However, a study by Dorevitch et al. (2015) found that measures of water quality were not predictive of gastrointestinal illness, and that frequent use of a waterway decreased the risk of disease, contradicting earlier studies. However, chronic gastrointestinal conditions may aggravate the risk of illness (Dorevitch et al., 2015). Studies have also shown no clear relationship between illness and any faecal indicator for non-sewage impacted beaches (Calderon, et al., 1991; Colford et al., 2007).

The objective of this study was to investigate potential public health risks posed by fresh and brackish water swimming sites in Hunter New England (HNE), NSW, Australia, and to promote preventive risk management. HNE stretches north-west from Newcastle on the NSW east coast to the Queensland border. The region covers an area of 131,785 square kilometres and has a population of over 873,741 residents. The numerical digits (1-7) in Figure 1 show the location of the seven swimming sites surveyed.

Figure 1: Location of the recreational swimming sites, rural Hunter New England Local Health District, December 2014.

Recreational water policy

In Australia, recreational water safety and quality guidance are published in the National Health and Medical Research Council's Guidelines for Managing Risks in Recreational Water 2008 (Australian Guidelines) (NHMRC, 2008). The Australian Guidelines recreational water quality grading is based on the risk of incidentally swallowing water by an adult bather rather than children, the immunocompromised or elderly who might require a higher degree of protection (Kamizoulis and Saliba, 2003; NHMRC, 2008). Currently, there are limitations in using indicator enterococci to estimate the risk of illness in fresh and brackish water to directly derive microbial assessment categories for fresh water in Australia due to lack of data (NHMRC, 2008). Globally,

> *"epidemiological data on fresh waters or exposures other than swimming (e.g., high-exposure activities such as surfing, dinghy boat sailing or whitewater canoeing) are currently inadequate to present a parallel analysis for defined risks. Thus, a single series of microbial values is proposed, for all recreational uses of water, because insufficient evidence exists at present to do otherwise. However, it is recommended that the length and frequency of exposure encountered by special interest groups (such*

> *as bodysurfers, board riders, windsurfers, sub-aqua divers, canoeists and dinghy sailors) be taken into account (chapter 1)".* (WHO 2003, Table 7, p. 70).

Recreational water quality guidelines recommend enterococci as the preferred faecal indicator organism in marine and fresh recreational waters for the assessment of faecal contamination (NHMRC, 2008; US EPA, 1986; WHO, 2003). Enterococci are used as indicators of environmental contamination because they are found in high concentrations in faeces, and exposure to enterococci has been found to have a clear dose-response relationship to swimmers' disease outcomes (Boehm and Sassoubre, 2014; WHO, 2003). The close correlation between elevated enterococci concentrations and gastrointestinal disease in recreational fresh and marine waters, and their abundance in human and animal faecal matter, have led to their widespread use as indicators of recreational water quality worldwide (Cabelli, 1983; Fogarty et al., 2003; US EPA, 2012; Wade et al., 2008, 2010). Enterococci are considered equivalent to *E. coli* in fresh water (WHO, 2003; Marion et al., 2010; Boehm and Sassoubre, 2014). Enterococci are preferred because of their ability to mimic many pathogens in recreational waters (US EPA, 2012); they provide a better correlation with rates of gastrointestinal disease (Cabelli et al., 1983); are capable of replicating in extra-enteric environments such marine beach sands and survive longer in such environments than faecal coliform bacteria (Byppanahali et al., 2012; Piggot et al., 2012; Badgley, Thomas and Harwood, 2011; Yamahara, Walters and Boehm, 2009; Ferguson et al., 2005; Hartz et al., 2008). Enterococci have been linked to opportunistic pathogens that have caused numerous infections (Morrison, Woodford and Cookson, 1997; Moellering 1992).

The presence of enterococci in fresh water has been regarded as evidence of both point and non-point source pollution or resuspension from environmental reservoirs because oligotrophic freshwater habitats do not support the growth of enterococci (Byappanahalli et al., 2012). Oligotrophic water exposes the enterococci to biotic and abiotic stressors like nutrient starvation and sunlight or resuspension from environmental reservoirs (Sinclair and Alexander, 1984; Byppanahali et al., 2012). Studies suggest hydrological activities, such as rainfall runoff, overflows and wave surges are among the main sources of enterococci that affect water quality in recreational waters (Boehm et al., 2009; Haack, Fogarty and Wright, 2003).

A limitation of faecal indicator bacteria monitoring is that they are not believed to be conservative indicators for some of the most essential sewage-derived pathogens including several enteric viruses (Field and Samadpour, 2007; Fujioka et al., 2015). Recent studies have linked enterococci densities from non-point source pollution and human health, particularly gastrointestinal illness and skin infection (Fleisher et al., 2010; Heaney et al., 2012; Sinigalliano et al., 2010). The dose-response relationship for skin illness was found only with enterococci samples analysed by membrane filtration (Sinigalliano et al., 2010). Other studies have found that enterococci may not be exclusively of faecal origin, which may confound accurate water quality assessments (Byappanahalli and Fujioka, 2004; Desmarais et al., 2002). Enterococci may be endogenous in sediments and soils and not exclusively of faecal origin (Byappanahalli et al., 2012). When the source of enterococci to surface waters is not faecal, their presence may not indicate a health risk (Boehm and Sassoubre, 2014).

Indicator organisms from non-faecal sources may result in water bodies being incorrectly classified as contaminated when the public health risk is not increased (Boehm et al., 2009). Faecal indicator bacteria concentrations may abruptly vary before monitoring results are available, resulting in contaminated waters being left open to swimming when they should be closed. Therefore, there is a need for supplemental indicator organisms that would be indicative of risk for a wide array of human pathogens and to provide better protection of public health (Fujioka et al., 2015). Other sewage-specific markers have been identified, including *C. perfringens*, various bacteriophages, Bacteroides, as well as human enteric viruses (Boehm et al., 2009; Fujioka et al., 2015). Sources of enterococci in recreational waters include sewage, agricultural and urban runoff, stormwater, direct input by animals via defecation, bather shedding, boats, plant debris (for example, wrack), polluted groundwater, soils, sediments, and sands.

Measuring the levels of enterococci by culture methods is likely to underestimate the risk of gastroenteritis caused by enteric viruses in recreational waters caused by contamination from mixed sources (Ashbolt et al., 2010; Schoen et al., 2011). Rapid enumeration methods (qPCR) to quantify estimates of densities of enterococci are more reliable predictors of norovirus and human health risk (Schoen and Ashbolt, 2010; Schoen et al., 2011). The literature also indicates that microbial source tracking methodologies to track host-specific sources of faecal bacteria (Hagedorn et al., 2011; Harwood et al., 2014), quantitative microbial risk assessments for estimating risk and defining microbial hazards, and predictive modelling to predicting concentrations of enterococci *in situ* by using statistical models (US EPA, 1999, 2012) are more accurate in reporting recreational water quality. Microbial source tracking (MST) is the concept of identifying the contributing sources the relative importance of each source of faecal pollution (Hagedorn et al., 2011; Harwood et al., 2014). More recently, speciation of *Cryptosporidium* in source waters is more common in water quality testing (US EPA, 2012).

The guideline values for recreational water quality are expressed in terms of the 95th percentile of numbers of intestinal enterococci per 100 ml and represent levels of risk based on the exposure conditions of the key studies (WHO, 2003). Enterococci are used as a regulatory parameter in the European Union (EU) Bathing Water Directive and other jurisdictions (WHO, 2018; European Commission, 2019). The Australian Guidelines have adopted the use of a matrix of the 95th percentile guideline values for microbial risk assessment categories and the sanitary risk assessment categories. The microbial categories start at a 95th percentile guideline value of less than 40 colony forming units (CFU) intestinal enterococci per 100 millilitres (40 CFU/100 mL) of recreational water representing a probability of less than one case of gastroenteritis in 100 exposures and negligible acute febrile respiratory illness (NHMRC, 2008, Table 5.7). The applied microbial water quality assessment categories are “A” (≤40 cfu/100mL), “B” (41-200 cfu/100mL), “C” (201-500 cfu/100 mL) and “D” (>500 cfu/100 mL).

Comparatively, USA EPA recommends a monthly geometric mean water quality indicator concentration be <33 CFU/100mL for enterococci freshwater, full-body contact beaches and should not exceed 61 CFU/100 mL (Hrudey and Hrudey, 2004. p. 81-380). The US EPA also recommends 35 cfu/100mL for a 30 day mean and 104 – 501 cfu/100mL for a single sample for marine waters (US EPA, 2012). The US EPA faecal indicator bacterial standards are based on the reported correlation between faecal indicator bacteria concentration and human gastrointestinal illness at recreational beaches impacted by effluent from public sewage treatment works (US EPA, 1986). The European Union recommends a guideline value of 100 CFU/100mL and an obligatory 200 CFU/100 mL for bathing waters (Kamizoulis and Saliba, 2003).

The Australian Guidelines encourage the adoption of a nationally harmonised management of the coastal, estuarine and recreational water through assessment and management of local factors that may lead to hazards. For microbial quality, the Guidelines recommend that recreational water is categorised by a combination of a sanitary inspection category and a microbial water-quality assessment category (Kay et al., 2004; NHMRC, 2008; WHO, 2006). Additional to site categorisation, the Australian Guidelines recommend regular monitoring and auditing of swimming sites (section 5.5) and management of microbial risks through public health advisories and warnings and pollution prevention strategies (section 5.6).

Sanitary assessments identify all potential sources of faecal pollution, although human faecal pollution tends to drive the overall sanitary inspection category for an area. The applied sanitary categories are 'very low'; 'low'; 'moderate'; high'; and 'very high'. A combination matrix of the sanitary and microbial risk assessment categories ranks the water into five classification bands of microbial quality from 'poor', 'fair', 'good' and 'very good' grades. Depending on the sanitary assessment category, concentrations of 200 enterococci per 100mL of water can be regarded as safe to swim. The use of a range of categories instead of a simple pass/fail approach, supports the principle of informed personal choice, and allows the setting of practicable improvement targets for high-risk areas, rather than an "across the board" target, which may result in a lower overall health gain (WHO, 2003, NHMRC, 2008). The assessment matrix enables authorities to decide on appropriate management actions and respond to contamination incidences. The assessment also provides incentives for local rectification actions and supports the publication of advisory notices (warning signs) to assist informed individual choice.

In regional NSW, along the coast, some marine beaches are monitored under the Beachwatch Partnership Program, an offshoot of the Beachwatch Water Quality Program initiated in Sydney in 1989 (NSW Office of Environment and Heritage, 2017). The program was in response to community concern about sewage pollution washing up on Sydney's beaches. The program provides daily pollution forecasts and the latest recreational water quality conditions across Sydney, Hunter, Central Coast and Illawarra beaches to help people decide when and where to swim. The program provides weekly star ratings and annual beach categories/grades for each monitored swimming site.

Water quality information and categorisation are not available for most inland swimming sites except for weekly blue green algae in major rivers and dams. In New South Wales (NSW), monitoring of swimming sites along rivers and creeks is relatively uncommon except for a few sites that are accessed via reserves and recreational parks. Monitoring of faecal contamination in inland waters is generally exceptional although some local governments, WaterNSW and NSW Inland Waters Parks have monitoring programs at selected swimming sites along dams and major rivers such as the Murray River which are designated for swimming. There are several NSW dams that are popular for swimming, boating and skiing, although with minimal microbial quality monitoring. Although minimal information and monitoring data is scarce, recreational freshwater sites have high recreational value in rural areas (Sinclair Knight Merz, 2011).

Method

Sanitary surveys were carried out, and enterococci densities were measured during the peak swimming season in NSW at seven swimming sites during December 2014 – February 2015. The period has increased bather loads in low flow recreational waters and thus poses the highest potential public health risk to recreational users. The period includes the most extended school holiday, high volume camping and rural festivals with an influx of tourists and hence high bather loads. The Tamworth Country Music Festival, for example, is an annual extended mass gathering in January with a flow of approximately 60,000 people, effectively doubling the population of the Tamworth region (Polkinghorne et al., 2012).

A risk matrix of the 'Sanitary Inspection Category' and the 'Microbiological Assessment Risk Category' was used to determine the overall 'Water Quality Grade' for each site. The study results were shared and discussed with the respective local authorities to promote water quality risk management options.

Ethics approval

Ethics approval was obtained from the NSW Human Research Ethics Committee (HNEHREC 13/10/16/5.06); NSW Human Research Ethics Committee (NSWHREC LNR/13/HNE/418) and James Cook University Ethics Committee (H5085).

Study site selection

A list of popular water recreational swimming sites was compiled using local knowledge from Environmental Health Officers in the Public Health Unit and respective Local Governments, Google satellite map searches and internet searching for events and festivals where recreational water use was likely. A convenience sample of seven study sites was then selected based on the following selection criteria:

- The site could be used for whole body contact such as swimming or water skiing;
- The ease of access for sampling such as driving conditions, walking time and ability to get the sample to the laboratory within 24 hours (DAL, 2010);
- The popularity and promotion of sites for swimming and recreational use;
- The occurrence of festivals (influx of people) in the area; and
- The size of the water body during summer with a preference for a low water flow/level

Sanitary Inspection Categories

Site management information, such as routine water quality monitoring, wastewater pump stations and discharge points, adequacy of onsite sewage management around the sites, and public advisories were sought from the Beachwatch Program (where present) and respective local government environmental health departments. Environmental Health Officers conducted sanitary inspections for each site before sampling for indicator enterococci based on the Beach Water survey tool (Department of Health, 2008; Office of Environment and Heritage, 2017). The inspection provided a qualitative assessment of the area's susceptibility to influence from human and/or animal faecal contamination to determine the sanitary inspection category. A desktop matrix of the likelihood and consequence of contamination from each pollution source was completed to determine the likelihood category for each swimming site. Each potential pollution source was then assigned a likelihood category: very low, low, moderate, high, and very high. To ensure consistency and integrity across the region the officers were trained in the use of the survey tool before inspections. The desktop Sanitary Inspection Category predicted the overall likelihood of a public health event occurring after swimming. A public health event can be conservatively defined as an occasion when a pollution source could cause enterococci levels greater than the illness threshold of 40 CFU/100 mL at a swimming site (Office of Environment and Heritage, 2017).

A sanitary report template (Western Australia, 2007) was used to identify the following potential sources of faecal pollution that were likely to impact on the respective swimming sites:

- Bather shedding (low flow, bather density)
- Sanitary facilities (leaks and relation to proximity, age, on-site treatment)
- Stormwater discharges (run off, sewage from overflows, animal faeces)
- Sewage overflows (points, age, capacity, serves large population)
- Sewage chokes and leaks
- Waste water reuse (treatment level, location, volume)
- Riverine discharges (where applicable)
- Number of boats/kayaks
- Animals (bird numbers, native animals, domestic animals) and
- Neighbouring land uses (agricultural activities, camping)

The likelihood was then assigned a quantitative numerical likelihood value according to the Australian Guidelines (Table 1). The likelihood values for all assessed pollution sources at each site were added to give a total likelihood category range, which was then compared with the Australian Guidelines category range values to determine the overall sanitary inspection category (NHMRC, 2008). For example Site X has 5 identified potential sources of pollution with likelihoods of very low, low, moderate, moderate and high. The overall likelihood would be 0.1+ 0.2 + 1 + 1 + 3 = 5.3 = Likelihood category range of 3 to <12. Therefore, the sanitary inspection category for the site is high (Table 1).

Table 1: Assessment of Likelihood Categories and values [2].

Likelihood category	Event frequency	Likelihood value	Likelihood category range	Sanitary Inspection Category
Very Low	1 in 10 bathing seasons	0.1	<0.2	Very low
Low	1 in 5 bathing seasons	0.2	0.2 to 1	Low
Moderate	1 per bathing season	1	1 to <3	Moderate
High	3 per bathing season	3	3 to <12	High
Very High	12 per bathing season	12	12 or greater	Very high

Microbiological Assessment Categories

At least twenty-five water samples were collected from each site for enterococci testing consisting of at least one sample every week for the duration of the study and planned to coincide with peak site usage activities such as festivals, high rainfall events or peak camping times. The remaining 13 samples were collected at peak usage days and times. The sample number was determined using the Australian Guidelines. The Guidelines suggest that fewer than 20 samples are insufficient. The samples were collected according to the NSW Guide for Submitting Water Samples to the Division of Analytical Laboratories for Analysis (DAL, 2010) to ensure consistency in accuracy and integrity across the region.

A sampling site environmental conditions survey was conducted at the time of sampling to assess bather loads, weather conditions, water flow, water transparency, the presence of faecal material, water discolouration; visible floating debris; algal blooms, boats, flocks of birds and other unusual activities or pollution factors. When two or more samples were collected, at least one was collected in the morning and one in the afternoon to capture the bather loads at different times of the day. This information could then be used to better explain the sampling results.

The samples were analysed by the NSW Forensic and Analytic Science Service laboratories using the Australian Culture-based Standard Method for Enterococci based on AS/NZS 4276.9:2007 (Standards Australia & Standards New Zealand, 2007).

The microbial densities were analysed using the EnteroTester Template V677 (EnteroTester®) to calculate the 95th percentile and geometric mean of numbers of *Enterococci* per 100 mL of water to obtain the microbial assessment categories (Lugg, Cook and Devine, 2012). The EnteroTester is a Microsoft Excel® template developed to estimate the infection risk for any given enterococcal distribution, and calculate a 95th percentile standardised to that of the reference distribution with the same risk. The standardised enterococci 95th percentiles allow direct comparison between different recreational waters regarding their infection risk. The standardised enterococci 95th percentiles overcome the common problem of misclassifying recreational waters to the wrong microbial water quality assessment category (Lugg, Cook and Devine, 2012). The EnteroTester® produces a narrower upper confidence band than the classic parametric method, therefore requiring fewer samples than recommended in the WHO Guidelines for Managing Risks in Recreational Water 2003 (Lugg, Cook and Devine 2012).

The EnteroTester® was specifically designed for Australian conditions (Western Australia, 2007). As recommended by the Australian Guidelines, the calculated 95th percentiles were then used to determine the Microbiological Assessment Categories for the respective swimming sites (NHMRC, 2008). The applied microbial water quality assessment categories are "A" (≤40 CFU/100 mL), "B" (41-200 CFU/100 mL), "C" (201-500 CFU/100 mL) and "D" (>500 CFU/100 mL) depending on the estimated threshold risk of gastroenteritis respectively (NHMRC, 2008).

Recreational Water Quality Grades

The overall Water Quality Grade for each swimming site was determined from a matrix of the 'Sanitary Inspection Category' and the 'Microbiological Assessment Category' for each site (Table 2). The grades ranged from very good, good, fair, poor, to very poor. Similar to the Beachwatch program, a 'traffic light' approach using green, amber, and red was included to describe and simplify the microbial safety of the swimming sites.

Table 2: Classification matrix for faecal pollution of recreational water environments by combining sanitary inspection and microbial assessment categories [2].

		Microbiological Assessment Category (95th percentiles - intestinal enterococci CFU/100 mL)			
		A <40	B 41–200	C 201–500	D >500
Sanitary Inspection Category (susceptibility to faecal influence)	Very low	Very Good	Very Good	Follow up	Follow up
	Low	Very Good	Good	Follow up	Follow up
	Moderate	Good	Good	Poor	Poor
	High	Good	Fair	Poor	Very Poor
	Very high	Follow up	Fair	Poor	Very Poor

Results

Two brackish water lagoons and five river swimming sites were assessed (Table 3). Six of the seven swimming sites were assessed to have poor quality water grades. All sites were impacted by riverine discharges and surface runoff. There were no obvious sewer discharges within a 1-km radius of the swimming sites. Only one site had water quality information or warning signs. Ducks, goannas, pelicans, and other birds were frequently found at the swimming sites. Bathers were frequently observed using the sites for recreational activities and swimming at the time of surveying and sampling.

Table 3: Description of the selected swimming sites, Hunter New England Local Health District, December 2014 to February 2015

Swimming site	Description
1	A freshwater waterhole 30 x 20 m along a river, 1 km upstream from the nearest town. Open to all ages. Sandy beach and rocky shores. Surrounded by rainforest. Hobby animal husbandry within a 1 km upstream. Picnic areas 200 m to the south. Toilets located at the picnic area but any overflow would flow downstream from the swimming site. No sewage outfalls or stormwater discharges. Main faecal sources would be general riverine discharges containing agricultural surface runoff and leaching from farm onsite wastewater management systems during wet weather. Birds, wallabies, and farm animals have free access. Not monitored for water quality.
2	A brackish coastal lagoon with a sandy beach, 5 km south of the nearest town. Very popular with all ages. Surrounded by rainforest. Open to diverse wild animals and birds including geese and flying foxes within 1 km radius. Deep gullies were situated within a 1 km radius to the lagoon. No sanitary facilities. Subject to sewer outflows from within 2 km. Subject to NSW Beachwatch and Hunter Water Corporation water quality monitoring programs. Daily water pollution forecasts available. Subject to riverine discharges and surface run-off.
3	A freshwater waterhole 70 x 30 m along a river about 800 m downstream from the nearest town CBD. Sports Grounds with sanitary facilities within 100 m to the north and south. Bridge over the swimming site. Hospital, commercial and industrial areas within 1 km radius. The land 1 km to the south is predominantly used for fodder cropping and irrigation with recycled industrial water relatively common. Open to all ages. No beach. Cleared and maintained surroundings. Sandy-loamy soils. No dedicated sanitary facilities. Suitable for kayaking but not boating. Fishing point. Three riverine discharge points within 1 km radius. Possible surface runoff into the site. No sewage outfalls. Stormwater drains directly into the swimming site. Horse racing track within 1 km but runoff discharges downstream of swimming site. Companion dogs swim at the site. Ducks frequent the site. No animals are within a 1 km radius. Not monitored for water quality.
4	Sandy Semi-brackish water lagoon. Open to all ages. Large grassy expanse. Caravan and Boat camp within 1 km upstream with sullage and drop pit toilets. Rainforest and

	mangroves. Abundant bird life. Fish cleaning table on the shore. More camping and a resort upstream. Animal husbandry and poultry farming further upstream. Minimal riverine discharges within a 1 km radius. Subject tidal flushing. Not monitored for water quality.
5	A freshwater 50 x 30 m river waterhole 500 m upstream from the nearest town CBD. Sandy beach. Open to all ages. Caravan park 50 m from the site. Fodder farm and hobby animal farming within 1 km to the south. Veterinary practice 400 m upstream. Flying fox colony about 200 m upstream. A stormwater drain discharges surface water and runoff directly into the swimming site. Two riverine discharges within a 1 km radius. Fishing point. No direct animal access. Ducks frequent to the site. Companion dogs swim at the site. Draw-off point for town drinking water supply. Maintained adjoining viewing point. Not monitored for water quality.
6	Freshwater river mountain pools situated in the foothills of a World Heritage Wilderness mountain range. Open to all ages. Sandy beach. Draw-off point for town drinking water. Rain forest bushes. Abundant wildlife. Privately owned Spa Cabins, lodge and camping sites within a 1 km upstream. Suitable for fishing and canoeing but not boating. Animal husbandry within a 1 km radius. Caravans have been observed running hoses on the ground discharging waste within 10m to the river. Toilet facilities available. Main faecal sources would be general riverine discharges containing agricultural surface runoff and leaching from cabins and camping site onsite water systems during wet weather. Birds, wallabies, and farm animals have free access. Not monitored for water quality.
7	River swimming site on the outskirts of a city. Clay- loamy soils. Jetty provided for easy access. Camping ground nearby. Served with deep sewer system with a sewer pump station. Cleared and maintained the recreational neighbourhood. Fenced farm grazing to the shores. Open for fishing, skiing and boating. Public Sanitary facilities available 20 m from the swimming site. Highly popular. Subject to storm water discharges. Minimal riverine and surface runoff discharges. Close to a drinking water draw-off point. Twice weekly water quality monitoring by local drinking water supply authority.

Weather conditions

The survey period was marked by a few relatively low rainfall events (Table 4). The coastal sites experienced more rain than the inland sites. Sites 3 and 5 had the highest mean enterococci densities despite low mean rainfall. Enterococci levels were higher after rainfall events (p = 0.0001 Fishers Exact Test). The temperature at the sites ranged from 36^0C to 18^0C with a mean of 26^0C and mode of 24^0C during water sampling times.

Table 4: Rainfall levels at fresh/brackish water swimming sites, Hunter New England, NSW, December 2014- February 2015.

Swimming site	Total rainfall (mm)	Mean (mm)	Range (mm)	Mode (mm)	Mean Enterococci density
1	131	5.8	45	27	678
2	187	6.9	54.8	15	69
3	73.3	2.9	30	7	1433
4	212	8.5	48.6	46	27
5	73.3	2.9	30	7	1044
6	119	4.8	29.7	9	784
7	128	5.1	31	5	79

Site risk assessment and sanitary inspection categories

Sanitary risk assessments for faecal contamination at all swimming sites except for Site 1 had moderate sanitary inspection categories. Swimming sites 2, 3, 5 and 7 had “High” sanitary inspection categories. Sites 1, 4 and 6 had “Moderate” categories. Swimming sites 3 and 5 had the highest likelihood values.

Microbiological Assessment

One hundred and eighty samples were analysed (Table 5). The water quality, measured as *Enterococci* colony forming count (CFU) at the seven swimming sites, was relatively poor. Enterococci levels were significantly higher in the afternoon when bather loads were higher compared to the morning (p = 0.002 Fishers Exact Test). Swimming sites 3 and 5 showed higher enterococci levels between 12/01/2015 and 28/01/2015, a festival period, more so in the afternoon than in the morning.

Table 5: Enterococci counts (CFU/100mL) descriptive statistics, fresh/brackish water recreational swimming sites, Hunter New England, NSW, December 2014- February 2015.

Swimming site	No. of samples	Mean count	Minimum	Maximum	Range	Std. deviation	Morning mean	Afternoon mean
Site 1	25	678	40	3900	3860	982	553	776
Site 2	25	69	0	390	390	112	120	5
Site 3	27	1433	10	9000	8990	2204	1197	1572
Site 4	25	27	0	370	370	73	13	42
Site 5	27	1044	14	5000	4986	1433	629	1289
Site 6	26	784	27	8000	7973	1621	365	916

Sites 2, 4, and 7 consistently recorded lower enterococci levels than the Australian guideline 40 CFU/100 mL per sample of water with a few exceptions. Swimming site 4 exhibited good water quality grade (Standardised 95th Percentile = 155; Geometric mean = 6.2 CFU/100 mL). Swimming site 6 had the highest enterococci counts (Standardised 95th percentile = 8800; Geometric mean 356.4 CFU/100 mL). Swimming site 3 (downstream from the town) exhibited poorer water quality (Standardised 95th percentile = 7200; Geometric mean = 437.6 CFU/100 mL) compared to upstream site 5 (Standardised 95th percentile 7000; Geometric mean = 405.5 CFU/100 mL). Water quality at Site 2 was better (Standardised 95th percentile = 280; Geometric mean 11.7 CFU/100 mL) than at site 7 although in the same Category C. Brackish water quality categories (Sites 2 and 4) fared better (Categories B & C) than freshwater sites (Category D) (Table 6).

Table 6: EnteroTester® Microbiological Assessment Categories for selected individual swimming sites in regional Hunter New England, December 2014 to February 2015 inclusive

Site Name	Number of Samples	Percent of samples less than 40 CFU/100 mL	Assigned Geometric mean	Assigned or Standardised 95th Percentile	Traffic light colour	Microbial Assessment Category
1	25	4	282.4	7600	Red	Category D
2	25	68	11.7	280	Amber	Category C
3	27	11	437.6	7200	Red	Category D
4	25	88	6.2	155	Green	Category B
5	27	7	405.5	7000	Red	Category D
6	26	4	356.4	8800	Red	Category D
7	25	48	50.6	340	Amber	Category C

Recreational water quality grades

A matrix of the sanitary inspection and microbial assessment categories indicated that only site 4 had a good water quality grade (Table 7).

Table 7: Recreational Water Quality Grades for selected individual swimming sites in regional Hunter New England, December 2014 to February 2015

Swimming site	Sanitary Inspection Category	Microbial Assessment category	Water quality grade
1	Moderate	D	Poor
2	High	C	Poor
3	High	D	Very poor
4	Moderate	B	Good
5	High	D	Very poor
6	Moderate	D	Poor
7	High	C	Poor

Sites 1, 2, 6 and 7 had poor water quality. In 2014, Beachwatch program classified site 2 as "Good" (NSW Office of Environment and Heritage, 2015). Water quality at site 7 is managed by local drinking water supply authority, but it is not graded for swimming purposes. The Beachwatch program assesses the water quality over a longer time frame. Sites 3 and 5 had very poor-quality water grades.

Discussion

The overall water quality grades at the swimming sites were 'Poor'. Enterococci levels were higher where faecal risk contamination was predicted by the sanitary inspections. The Sanitary Inspection and Microbial Assessment Categories suggested that all but one swimming site were not sanitarily safe enough for swimming. The sampling time (morning or afternoon) and rainfall also seemed to influence the enterococci densities.

Faecal contamination sources

All the assessed swimming sites were free from obvious sewage discharge areas within a 1-kilometre radius. However, sites 3, 5 and 7 were in urban environments where sewer overflows were probable. Sewer overflow data was not obtained from the respective authorities. In developed countries like Australia, urban sewage is typically treated before discharge although leaks and overflows from sewerage systems following rainfall events may cause problems (Sercu et al., 2009, 2011).

All the sites had animal activity, including birds and wildlife, in the immediate neighbourhood. All the sites, except for site 2 were influenced by livestock (sheep and cattle) either in the immediate vicinity or upstream. The stocking levels were not determined. Site 5, had a large flying fox colony 200 m upstream and had a very poor water quality grade together with site 3 (about 2km downstream). These two swimming sites had higher enterococci counts in the afternoon when flying foxes were present in their colonies compared to the morning just after they had been away from site foraging during the night. Pathogenic bacteria including *Salmonella* and *Campylobacter* have been reported in the Parramatta River where many bird species are present (Antilles et al., 2015; Cody et al., 2015; Ramonaite et al., 2015). Several studies have demonstrated that wild birds are the predominant source of faecal material containing *Clostridium jejuni*, including strains associated with human disease (Cody et al., 2015; French et al., 2008). At a site where enterococci were believed to be from birds and runoff in Mission Bay, California, swimmers' illness did not correlate with enterococci density, but an association between skin rash and *Enterococcus* was observed (Fleisher et al., 2010; Sinigalliano et al., 2010). A range of human pathogenic (and indicator) microorganisms have been detected in the faeces of domestic animals and wildlife including kangaroos, wombats, wallabies, possums, wood ducks, rodents, pigs, deer, cats, and rabbits (Cox et al., 2005). Enteric viruses are also widely believed to cause of recreational water illnesses (WHO, 2003) although studies have neither incorporated methods to confirm their aetiology nor enumerated them (Boehm et al., 2009).

Swimming in dams, rivers, or lakes in NSW has been associated with cryptosporidiosis (Puech et al., 2001). Notification data suggest environmental factors such as temperature (seasons), remoteness (distance from urban areas), proximity to animals and sanitation are important predictors of such diseases (Lal et al., 2015). A study in Australia found that recreational water catchments where swimming and camping occurred showed a predominance of *C. hominis* compared to non-recreational catchments which had a higher prevalence of *C. parvum* (Loganthan et al., 2012). However, *Cryptosporidium* can also be transmitted by direct person-to-person transmission, zoonotic transmission, foodborne transmission, drinking water or swimming pools (Fayer and Gannon, 2004; Ng et al., 2012; Xiao, 2010). The relative importance of the different transmission routes is still unclear as most species of *Cryptosporidium* are morphologically identical and cannot be differentiated through routine microscopic diagnostics in pathology laboratories (Ng et al., 2012). The required molecular genotyping is infrequently carried out (Xiao, 2010).

Non-faecal contamination sources

When the source of enterococci is not faecal, their presence may not indicate a health risk (Boehm and Soller, 2011). Moreover, health risks cannot be determined based only on the measured concentrations of enterococci in recreational water samples without establishing a connection between faecal enterococci concentrations and bather illness (Dorevitch et al., 2010; Fujioka et al., 2015). Epidemiologists have studied the correlation between swimmer illness and enterococci densities in recreational waters not impacted by wastewater, but the results remain unclear. The Australian Guidelines note the limitations of using indicator bacteria to estimate the risk of illness in fresh and brackish water because of lack of data (NHMRC, 2008). It is not possible to directly derive microbial assessment categories based on disease outcomes for fresh water. Significant differences exist in swimming-related gastrointestinal illness rates in marine swimmers compared to freshwater swimmers at a given level of faecal indicator organisms (NHMRC, 2008). Illness rates reported for seawater swimmers were twice as high as for freshwater swimmers (Dufour, 1994; WHO, 2003). Epidemiological study data support this relationship, although the research groups used very different methodologies (Ferley et al., 1989; Kay et al., 1994).

Therefore, applying the microbial assessment categories derived for sea waters to brackish or fresh waters is likely to result in a lower illness rate in freshwater users, providing a conservative guideline in the absence of suitable epidemiological data for fresh waters (NHMRC, 2008 p.74).

Bather shedding presents a health risk. Studies elsewhere have found that the observed incidence of illness in swimmers was not necessarily related to background concentrations of indicator organisms, but rather to microorganisms shed during recreational contact (Loge et al., 2009). Globally, epidemiological studies support the positive association between concentrations of *Enterococci* and rates of swimming-related illnesses in fresh and marine waters (Wade et al., 2006, 2008). However, other epidemiological studies at swimming sites contaminated by non-point sources of faecal indicator bacteria found no association between faecal indicator bacteria levels and swimming-associated gastrointestinal illness (Colford et al., 2007; Fleisher et al., 2010; Pusch et al., 2005; Sinigalliano et al., 2010;). Swimmers may also be exposed to other infections. For example, *Pseudomonas aeruginosa* may cause infection of ears, skin, eyes, nasal cavity, and respiratory tract (WHO, 2006).

Weather conditions

Concentrations of enterococci in rivers rarely exceed 10^3 CFU per 100 mL (Ran et al. 2005) but may be elevated in response to meteorological events (Haack et al., 2003). Urban rainfall runoff has been associated with significant faecal enterococci contamination of recreational waters (Cho et al., 2010; NSW Office of Environment and Heritage, 2011). Multiple regression analyses have found that rainfall accounted for between 15 and 66% of bacterial density variability in water bodies (Hose et al., 2005).

Drought conditions that prevailed across inland Hunter New England region influenced flows and quality in the river systems during the study period. Enterococci densities were higher after rainfall indicating that riverine, and storm water outflows affected the water quality. Rainwater runoff and irrigation, and agricultural activities can contain extremely high enterococci concentrations that can sometimes surpass concentrations measured in raw sewage (Olivieri et al., 2007; Reeves et al., 2004).

Short-term fluctuations in pathogen densities can markedly change health risks for recreational water users. Rainfall increases the flow rate of rivers, causing resuspension of small particles like clays, which raise water turbidity. If the particles had microorganisms adsorbed onto them, they would also be suspended (Boutilier et al., 2009; Jamieson et al., 2005), representing a potential risk of infection (Chandran et al., 2011). In the Swan and Canning Rivers, Western Australia (WA), rainfall events of more than 5 mm have been strongly associated with elevated enterococci densities during five consecutive bathing seasons of November 2010 to April 2015 (Gunady, Koutsoukos and Theobald, 2016). Other studies found that enterococci levels between 201 to 500 MPN/100 mL were associated with rainfall ranging from 3 to 21 mm, values between 501 to 700 MPN/100 mL were associated with rainfall ranging from 9.4 to 30 mm. Elevated levels over 700 MPN/100 mL were associated with rainfall ranging from 12 to 35 mm (Gunady et al., 2016). Fast river flows may result in low solid concentration in water that may deprive enterococci (microorganisms) particles to attach to, leading to an eventual transport to other parts of the river, inactivation or death (Gutierrez-Caccibue et al., 2014).

Site management

Currently, NSW Health recommends that people do not swim in estuaries or rivers for the three days following heavy rain (NSW Health, 2015). Microbial assessments showed that site 4 was in category B (Green) and sites 2 and 7 were in Category C (Amber). Although Site 2 ended up with a poor water quality grade, it shows that coastal swimming sites may be impacted positively by tidal waves which dilute the microbial contamination. Site 7 was a drinking water source; therefore, water quality was monitored and managed by local drinking water supply authority. Although Site 5 was a draw-off point for drinking water, the water quality grade was very poor. There was a flying fox colony 200m upstream. Hence the microbial assessment category was D (Red). The responsible local government, together with other stakeholders, including the local Public Health Unit, has since obtained permission to cut the habitat trees shorter to move the bat colony away from the site. The Public Health Unit has also engaged the other local governments in the area to at least install water quality information and warning signs at known swimming sites. The Public Health Unit has suggested and engaged with the respective local governments and the NSW Crown Lands and Water to develop and implement water quality risk management protocols for popular swimming sites. It is necessary to keep a systematic water quality management system to minimise swimming sites water pollution (WHO, 2006). Unlike urban environments, regional sites may be more prone to animal faecal contamination than human. Rural freshwater swimming sites may be more prone to non-point contamination sources than urban coastal sites which are more prone to sewage contamination.

Limitations

Available resources, including staffing, travel distances and cost of water testing, limited the sample size. The study occurred during a dry summer season with little rainfall. The effects of storm water and riverine discharges were minimal, especially for freshwater sites, which are usually affected by urban and agricultural runoffs. The results may thus not be a true reflection of the water quality in a typical wet summer season when the river flows are faster. The study was based primarily on the beach water survey design. No appropriate freshwater study design could be accessed. Enterococci are not directly applicable to fresh and brackish waters (NHMRC, 2008). Challenges are presented when applying the Australian Guidelines and may limit the ability to conclude definitively that all sites were not suitable for swimming. Further research would be required to determine the extent to which freshwater recreational activities contribute to the burden of regional enteric diseases and the public health importance of swimming in such unregulated sites.

Conclusion

Popular recreational water sites in regional Hunter New England have poor quality water grades, from ‘fair’ to ‘very poor’. Freshwater recreational sites had more elevated enterococci levels than semi-brackish water sites. The study points to the potential public health risk in the absence of adequate policy infrastructure and demonstrates the need for responsible authorities to control the use of popular inland swimming sites, especially after heavy rainfall. Local water authorities need to provide oversight and public awareness over the use of recreational water sites. Recreational users need to be adequately informed about water quality and potential public health risk at all popular swimming sites in the region especially through warning signs, and information on local recreational web sites.

Implementation of the NHMRC’s 2008 Guidelines for Managing Risks in Recreational Waters in regional recreational water sites may not be feasible without adequate knowledge about the risk posed to recreational users. The high enterococci densities found suggest that other microorganisms, like virus and parasites, may be also present representing an immense public health concern risk for public health. Further research to understand the microbial communities and their health effects will improve the ability to assess public health risks and for the development of effective water quality guideline values based on freshwater indicator microbes.

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Plate 6.2 Drinking water source point used as a recreational swimming site, Paradise Park, Tamworth, NSW, 2014

Chapter. 7 General Discussion

7.1 Overview

This thesis has been based on practitioner-led research, and aims to close the gap between research, policy and practice. This chapter discusses how this concept was used in environmental health work to improve drinking water quality in regional Hunter New England, New South Wales (NSW), Australia. Several studies have investigated stakeholder consultation and involvement in research, but literature on partnerships between academics, policy makers and communities and environmental health officers and their impact on environmental health practice is scarce. The Australian Drinking Water Guidelines 2011 provide guidance for water utility action to promote stakeholder participation (NHMRC, 2011, element 9 p.52) but this is rarely enacted in environmental health practice in NSW. For example, a review of drinking water quality in regional NSW in 2007, (Cretikos et al., 2010) determined risk factors for microbial noncompliance by analysing routinely collected data but did not incorporate community groups and academic researchers. The literature indicates that engaging stakeholders in a participatory research approach strengthens the evidence and optimizes its uptake in practice (Bowen and Graham, 2013; Wilkinson et al., 2012).

The current research project was based on four projects (Chapters 3-6) undertaken to illustrate the use of routinely collected data. The presence of databases such as the NSW Drinking Water Database, provided the opportunity for undertaking research and policy interventions on environmental health determinants such as drinking water quality. Modern systems for data collection can be exploited to benefit environmental health research and practice.

NSW Health acknowledges the importance of promoting a culture of collaboration, in order to motivate research and accelerate policy and practice change (Chant, 2018). NSW Health strongly supports evaluation as a way to appraise the efficiency, effectiveness, appropriateness and sustainability of policies and programs (Centre for Epidemiology and Evidence, 2018). Environmental health practitioners/researchers hope that their research will inform policy and decision-making, underpinning and influencing the development of sound water quality policy. However, having a credible cause is not always sufficient to capture the support of decision-makers (Roxon, 2017). Consistent translation of health research knowledge into practice is limited (Wallace et al., 2012).

The implementation of evidence-based practice and policy is often hampered by differences in the principles of research, policy, and practice (Lewig et al., 2006). Researchers often wonder why policy-makers resist change, despite the reporting of convincing evidence, while policy-makers complain that many researchers do not make their evidence user-friendly and practitioners habitually just follow the their organisations' policy irrationally (ODI, 2004). Such differences create barriers for translating research evidence into policy decisions and the implementation of interventions to improve public health. The Australian Healthcare and Hospital Association has championed the Deeble Institute for Health Policy Research as a worthy vehicle for clinicians, researchers and policy-makers to turn collaborate research evidence into a better health system (Cole, 2017).

Decision-makers often prioritise projects that engender value to public health service in the short term without direct budgeted research costs (Ramsberg and Platt, 2017). The National Health and Medical Research Council (NHMRC) highlights the translation of research into health practice as a strategic priority (NHMRC, 2018) and has established precise measures to support the translation (Thackway et al., 2017). Practitioner-led research facilitates communication about the intent of the program, its rationale and the causal linkages between stakeholders and policymakers, including establishing the public health program among competing issues, problems and resources (Cooksey et al., 2001). Common understanding generates the sharing of ideas, allows open and critical discussion on the program, and facilitates the generation and consideration of alternative strategies. It also identifies assumptions and makes assumptions explicit (Millar et al., 2001). Currently, in research, attention is focusing on the concept of 'comparative effectiveness', which is defined as research evidence constructed to appraise policy outcomes by offering routinely collected data on the impacts on public health delivery (Bloomrosen and Detmer, 2013).

Water Organoleptics or aesthetic quality (taste, odour and colour) are usually the strongest lay predictors of drinking water quality outside any scientific tests (NHMRC, 2011; Doria et al., 2005; MORI, 2002). Appearance, taste and odour are useful indicators of quality because they are generally the characteristics by which the public judges water quality. Even if the water quality meets the ADWG, if the intended consumers do not drink the water then there are no complaints and the supplier may never be fully aware of nor understand consumer opinions regarding the water supply. Interpersonal communication, familiarity with water sources and a memory of past events about water quality or safety also influence consumer perceptions (Doria et al., 2005; Park et al., 2001; Saylor and Prokopy, 2011). To our knowledge, no other research testing these propositions has been carried out in the Hunter New England region or in NSW. Community engagement and participation in the provision and management of the safe town water supply empowers consumers and encourages the community to accept the supply.

7.2 Journal Publication

The manuscript discusses the concept of practitioner-led research and illustrates how the concept was used in routine environmental health work to bridge policy, research and practice. The engagement of policymakers in the project ensured that the outcomes were implemented throughout NSW, rather than simply in the Hunter New England region. The involvement of academic researchers ensured research rigour.

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Using practitioner-research to bridge policy, practice and research in drinking and recreational water management in rural Hunter New England region, New South Wales, Australia

Abstract

One of the central elements of a learning health system is to analyse and translate routinely collected data to generate knowledge which can then be used to improve health. In rural New South Wales, drinking water quality improvements have resulted from application of routinely collected data in practitioner-led research. Common databases, such as the New South Wales Drinking Water Database, provide powerful data with the potential for policy interventions on environmental health determinants.

Environmental health practitioner-led participatory action research in collaboration with managers, academics and environmental health practitioners was used to bridge policy research and practice gaps. The evidence was translated by consensus into actionable outcomes which were disseminated through institutional reports to policy-makers; co-authored peer-reviewed publications; presentations at professional conferences; and partnerships and collaborations with other institutions, especially local governments.

The structure of the research created a culture of "shared responsibility" in which practitioners, academic researchers, and policy-makers incorporated the concept of a service system; a shared understanding of the nature of evidence, and worked together towards the goal of shared decision making. Practitioner-led research can be nurtured within a learning set whereby academic experts, mentors and peers support policy relevant projects. The positive relationships and outcomes can also be extended to other health protection programs and activities such as air quality, contaminated sites, food hygiene, tobacco control, skin penetration or legionella control.

Introduction

Environmental health practice is a branch of public health concerned with identification, assessment, monitoring, evaluation, prevention, control and regulation of the physical, chemical and biological factors and conditions in the environment, which can affect human health and well-being (Sharp, 2003). Enforcement of existing policies and regulations for drinking water quality, recreational water use, sanitation, toxicology, microbial control, skin penetration, air quality, food safety, disease control and housing are traditionally central to the functions of an environmental health practitioner (NSW Health, 2017). Historically, environmental health practitioners are practice-based and not research focused. As a result, consistent environmental health research and translation of research knowledge into practice is often limited (Wallace et al., 2012).

One of the central elements of a learning health system is to gather, analyse and translate routinely collected data to generate new knowledge which then can be used to improve health (Institute of Medicine, 2012). Drinking water quality is a fundamental environmental determinant of public health (NHMRC, 2011). The Australian Drinking Water Guidelines 2011 (ADWG) directs safe drinking water management and includes a risk-based *Framework for Management of Drinking Water Quality* (NHMRC, 2011). In New South Wales (NSW), Australia, provision of safe drinking water is a partnership between water supply utilities and the local public health units. Water utilities are responsible for the safety of the drinking water they supply to consumers. NSW Health is the public health regulator of drinking water.

Using an environmental health practitioner-led research approach to influence policy and practice for drinking water quality management in the Hunter New England (HNE) region of NSW has been adopted and some lessons were learned (Jaravani et al., In review[a]). Although practitioner-led research is well developed in other health disciplines such as medicine and nursing (Institute of Medicine, 2012), there is very little published environmental health practitioner-led research in Australia.

Setting

In NSW all water utilities carry out routine monitoring of drinking water microbiological and chemical quality according to the Australian Drinking Water Guidelines 2011(ADWG) (NHMRC, 2011) to ensure its safety. Drinking water microbiological compliance is verified by the NSW Health Drinking Water Monitoring Program (Program) (NSW Health, 2005). The Program supports water utilities with free testing, guidance on sampling and protocols for responding when contamination is detected to ensure the safety of drinking water. This Program intends to provide a mechanism for NSW Health to exercise public health oversight of water utilities by ensuring an adequate and representative number of samples, at ample frequencies and appropriate locations in the distribution system that can monitor variability in the drinking water quality (Byleveld et al., 2016). The frequency of sampling is determined according to the population served and the complexity of the supply system. For compliance with the ADWG, a water sample must not contain *E. coli*. The Drinking Water Monitoring Program manages the web-based NSW Drinking Water Database (Database) centrally, and has recorded more than 20,000 sample results per year since 2001 (Byleveld et al., 2016). Therefore, there is sufficient routinely collected data to assess drinking water quality in NSW.

Diligent development and implementation of quality assurance plans including critical control points monitoring supports the know-your-own-system approach and continues to be the best-practice preventive strategy in NSW (NHMRC, 2011; Hrudey & Hrudey, 2014; Byleveld et al., 2016). The Program helps to monitor and assess any variability in the drinking water quality and provides a mechanism for NSW Health to exercise public health oversight of water quality (Byleveld et al., 2016). End-point (verification) drinking water monitoring helps to detect risks with the benefits of oversight perspective to understanding what improvements might ensure safer drinking water in the future, although people are already exposed by the time tests results are known (Hrudey & Hrudey, 2014). Assessment is a form of appraisal, which contributes to the protection of the public health by promoting improvement of the quality and safety of water supplies (NHMRC, 2011). It is both preventive (detecting risks) and remedial (recommending prompt corrective action and/or policy changes) before disease outbreaks may occur.

Practitioner-researcher approach

Global research has shown that it takes 17 years for 14% of research evidence to influence practice and the implementation of evidence-based interventions is often incomplete or ineffective (Lee, 2007). Advantages of practitioner-led research include a research agenda motivated by knowledge of service settings and consumer needs; the ability to draw on and value practice skills; and knowledge of how institutional data are generated, and its rigour (Institute of Medicine, 2012). Practitioners are often better placed than career researchers to develop collaborative relationships with stakeholders (Institute of Medicine, 2012). Practitioner-led research is integral to the outcomes of the practitioner's work culture and minimises the interval between evidence generation and improvement of public health service delivery (Thackway et al., 2017). Decision-makers in public health often prioritise projects that generate value to public health delivery systems without additional direct budgeted research costs and disturbance of routine service delivery (Ramsberg and Platt, 2017).

Practitioner-research is also referred to as ‘embedded research’ (Ramsberg and Platt, 2017) and encapsulates the notion that strongly linked policy, practice and research leads to more solid evidence translation. This, in turn, promotes good value-based service delivery in public health (Ramsberg and Platt, 2017). Environmental health practitioners often work with communities. Incorporating the beneficiary communities in the research process will enhance the research outcomes. Qualitative researchers term such stakeholder participation as “Participatory action research” (PAR). Practitioner-research is a method that can utilise PAR as an approach to research rather than a research method (Pain, Whitman, Milledge and Lune Rivers Trust, 2011).

The PAR approach seeks to shift the balance of power from practitioner-researchers to the people who are most affected by a program (Patton, 2008). The communities with feel empowered and own the outcomes as the product of their efforts. PAR seeks to primarily involve stakeholders, while empowerment evaluation aims to create a sense of ownership (Campbell et al., 2004; Secret, Jordan and Ford, 1999). In the approach, the participant is an equal partner with the practitioner-researcher (Boyle, 2012; Patton, 2008). This approach is linked to action, and ideally leads to the people or communities that are affected by the issues, having increased control over their lives (Baum, MacDougall and Smith, 2006). The active involvement of practitioners and stakeholders as co-researchers in the PAR approach encourages self-determination, strengthens community capacity and leads to more sustainable improvements in program delivery (Schwandt and Burgon, 2006; Patton, 2008).

Participatory action research using mixed research methods is the basic research approach used in the HNE adoption of the environmental health practitioner-researcher. Policy-makers (government departmental managers), academics (researchers), departmental staff, local government (water utilities) and the community were the stakeholders incorporated as co-researchers. We engaged environmental health practitioners, academic researchers, water utilities management and staff, NSW Health, NSW Office of Water, a local Aboriginal community, National Parks and Wildlife Service and Crown Lands Trust and specialist water engineers.

The research structure created a culture of "shared responsibility" in which practitioners, researchers and policy-makers incorporated the concept of a learning service system (Institute of Medicine, 2012), a mutual understanding of the nature of evidence and worked together towards the goal of shared decision making (Bloomrosen and Detmer, 2010).

Recognising that research skills are not core skills for environmental health officers, the environmental health officer-researcher developed research skills during their PhD training. An 'Adopt and Intervene as-we-go' philosophy was embraced. The evidence was interrogated, adopted and interventions identified applied and evaluated when they arose during the research process.

Four research projects (Figure 1) were undertaken to explore and bring about change in drinking water quality management through advocacy. These projects were:

- Using routinely collected microbiological water quality data for reticulated water supplies to improve drinking water quality management within the existing work budgets;
- Collecting data to assess and improve private drinking water safety management;
- Participatory Action Research with a local discrete Aboriginal community to understand drinking water perceptions and encourage consumption of safe water supplies; and
- Piloting enterococci testing to assess recreational water at popular swimming sites.

The first three projects were linked to the NSW Drinking Water Monitoring Program (NSW Health, 2005) and/or reflected back to the quality of drinking water in the HNE region, but the recreational water quality project involved some sites which were not drinking water sources. To illustrate the link between projects: project one used utility routinely collected data to assess compliance with the statewide water quality management systems. It was realised that the data did not include private water supplies. A separate project was designed to assess private water supply quality using recreational parks' water provision as an example. On evaluating the success of the follow-up project it was realised that some discrete communities preferred private rainwater to reticulated supplies. Using an Aboriginal community as an example, a follow-up project explored the reasons behind the drinking water choices in a discrete community.

Literature had shown that recreational waters in rural areas were more linked to waterborne gastrointestinal infections than drinking water (Puech et al., 2001; Dale et al., 2010). Client organisations, like local governments, were identified and incorporated into the research process. Stakeholder participation was crucial in executing the projects, although there were expressions of reservations about privacy and confidentiality regardless of ethical assurances.

All projects were carried out under the purview of environmental health practice rather than purely on academic research perspective. We characterised our research partnership as a shift from the more traditional hierarchical model of service delivery towards "equal-partnership" where the researchers and benefactors had agency and voice (Higgins et al., 2018). Central to the research model was a shared philosophy of community benefit. The relationship between problems, solutions and practice, enfold and embrace the whole cyclical process of action research at every stage (Osei-Bryson and Barclay, 2015). Efforts within this process were focused on increasing collaborative work with a diverse range of stakeholders through networking, attending service and agency meetings, and inviting representatives to participate in internal meetings.

The projects were sequential but revolved around drinking water quality management. Informal, unstructured face-to-face stakeholder consultations were undertaken to understand organisational perspectives on drinking water supply, needs assessment, and how the study project would benefit the respective organisations. Each project was developed and adapted based on the results of the consultations and needs assessments. The respective organisations identified volunteer point persons to participate in the project with management involved in non-participatory observations.

Each project was carried out in a continuous work cycle involving the following steps:

(1) Problem recognition and definition of an improvement opportunity in the client organisation, planning and designing a project to affect the improvement;

(2) Consulting and explaining the objectives and benefits of the project to the client organisation;

(3) Designing research questions to meet the expectations of the participants and the community served;

(4) Collecting, analysing and adopting evidence with the client organisation;

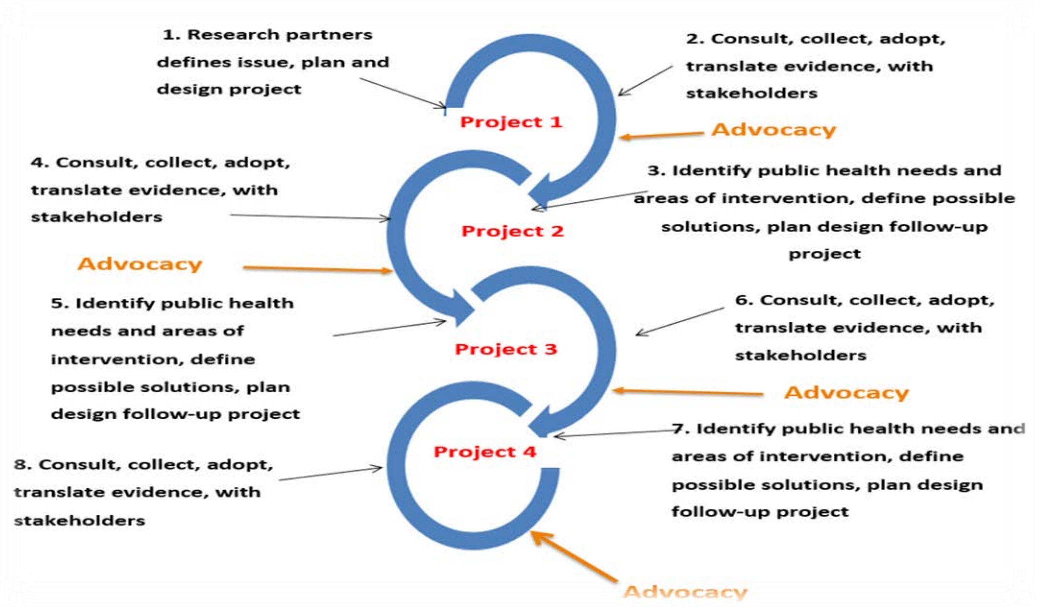
(5) Translating the evidence and identifying a possible solution;

(6) Taking action to realise the health benefit based on consensus between the practitioner, policy makers, academic researchers and the client organisation;

(7) Reviewing and advocating for policy change

(8) Identifying and designing a follow-up project to solve any identified shortfalls (Osei-Bryson and Barklay, 2015) (Figure 1).

Figure 1: Cyclical intervention-as-we-go participatory action project design and implementation



Legend:

Project 1: Working with departmental staff to assess drinking water quality utilising routinely collected data.

Project 2: Working with recreational parks authorities to improve private drinking water supply quality and safety.

Project 3: Working with an Aboriginal community to assess reticulated drinking water supply quality and acceptance and promote consumption of safe drinking water.

Project 4: Working with departmental staff to assess water quality at undesignated recreational swimming sites and advocate for policy changes to reduce public health risk.

Project 1: Using routinely collected data to improve drinking water quality

The approach was to analyse routinely collected data to generate evidence for policy change in drinking water service delivery (Bloomrosen and Detmer, 2010). Data generated for performance monitoring purposes are progressively used for research purposes and to improve service delivery quality and service planning (Ramsberg and Platt, 2017). Such practitioner-led research can translate into routine practice to minimise the interval between evidence generation and improvement of public health service delivery (Thackway et al., 2017).

Routinely collected drinking water monitoring data for the HNE region from 2001 to 2015 inclusive were assessed for sampling adequacy and *E. coli* detections, as a means of assessing the impact of the drinking water monitoring program (Jaravani et al., In review[a]). In this study, sampling adequacy refers to the proportion of the collected samples to the number of samples allocated per water supply system.

Since 2001, sampling adequacy and *E. coli* detections have improved significantly (Jaravani et al., In review[a]). The results suggest that the NSW Health Drinking Water Monitoring Program (policy), coupled with the development, implementation and response to drinking water management systems required by the *Public Health Act 2010* (NSW Government, 2010) has been effective in improving drinking water quality in the HNE region (Jaravani et al., In review[a]). The regular follow-up by public health units, improved reporting, early detection and correction of problems, a greater focus on treatment (including disinfection), and continuous infrastructure upgrading all contributed to safer drinking water supply.

However, despite the improvements, there have been some further issues which needed to be addressed to add value to the Program including:

- Sampling adequacy was significantly lower for supply systems serving less than 100 people (IRR = 0.83, 95% CI 0.70-1.00, p=<0.036);
- *E. coli* detection rates were significantly higher in smaller communities than larger communities (IRR 4.25 [95% CI 1.37-13.20], p=0.0123);
- *E. coli* detections were significantly higher in summer (IRR 2.68 [95% CI 1.73-4.17], p= <0.0001); and

- There was a strong inverse correlation between sampling adequacy and *E. coli* detection. The correlation may be attributed to a more competent, better resources management systems and the corrective actions following *E. coli* detections and ensuing vigilance rather than directly to improved sampling adequacy (Jaravani et al., In review[a]).

Project 2: Collecting data to evaluate private drinking water quality in recreational parks

Waterborne gastrointestinal disease outbreaks rarely occur in public reticulated water supplies in NSW. However, occasionally there are outbreaks attributed to private water supplies seriously impacting on consumers (Cowie and Byleveld, 2003; Merritt et al., 1999).

Most of the recreational parks in the region are not supplied with town water but have independent (private) water supplies such as rainwater tanks, rivers and bore water which may not be treated. Two concurrent assessments of water quality in recreational parks found that collaborative work between recreational parks authorities and NSW Health resulted in significant improvements in the provision of water quality warning signs (from 60% to 91%) and implementation of water quality assurance programs (from 7% to 100%) (Jaravani et al., 2015; Jaravani et al., In review[b]). NSW Health has also published amended Private Water Supply Guidelines that require the development of quality assurance plans by the *NSW Public Health Act 2010* (Jaravani et al., In review[b]).

Project 3: Participatory Action research with an Aboriginal community to assess reticulated drinking water acceptance in an Aboriginal community

Participatory action research approach was used in partnership with a particular discrete Aboriginal community to understand the community's perceptions of the town water supply and then investigate and explore possible solutions to identified problems together (Jaravani et al., 2017).

Inadequate water supply and sewerage systems have been identified as a major factor in the poor health status of some Aboriginal communities (NAHSWP, 1989). Across NSW, there are several discrete communities that are responsible for managing their drinking water systems but are supported by the NSW Aboriginal Communities Water and Sewerage Program and are integral to the NSW Health Drinking Water Monitoring Program (Byleveld et al., 2016). A discrete Aboriginal community in NSW is one parcel of Aboriginal community owned land that is predominantly inhabited and managed by Aboriginal people.

The collaborative work (Jaravani et al., 2017) found that:

- Reticulated (Public) water supply in the community met the ADWG 2011 microbial guidelines;
- The majority of the participants chose to rather drink untreated rainwater but were aware that the reticulated water was microbiologically safer than rainwater; and
- Societal influences, water hardness and taste, influenced the preference for untreated rainwater.

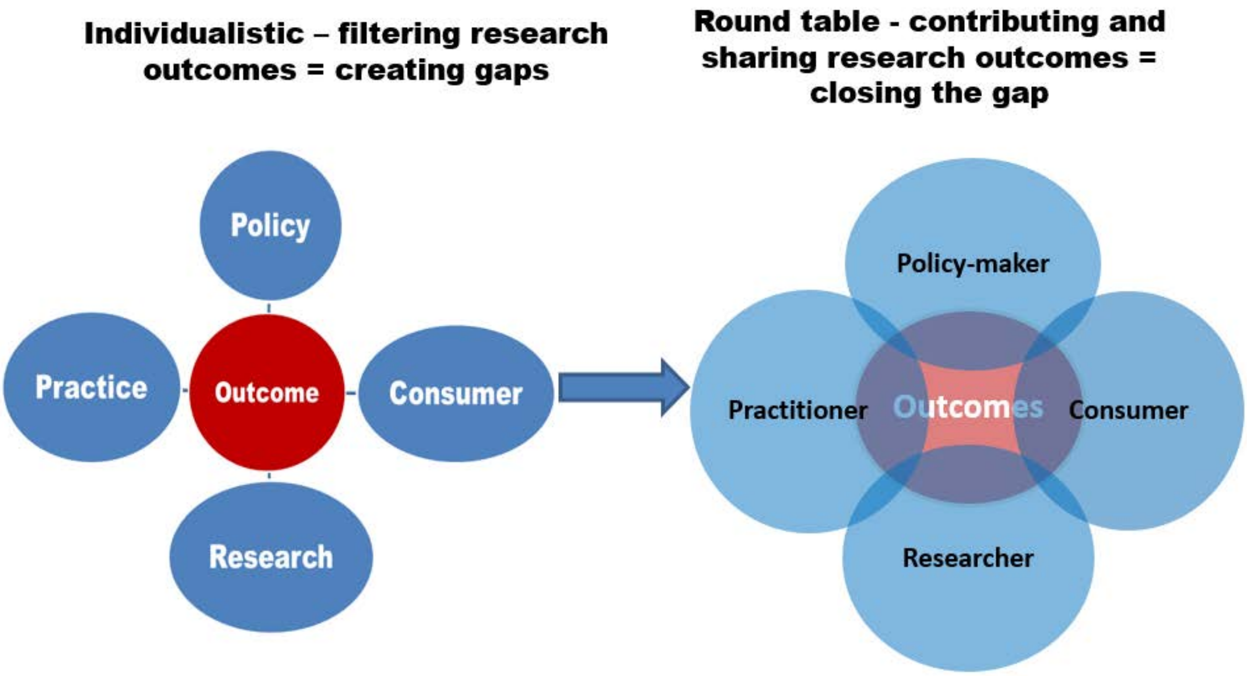
Project 4: Utilising the EnteroTester Template V677 to assess recreational swimming water quality

Drawing drinking water from recreational swimming sites may present challenges in treating the water to meet the Drinking Water Guidelines. The EnteroTester Template V677 was used to investigate potential public health risks posed by fresh and brackish water swimming sites in Hunter New England (HNE), NSW, Australia, and to promote preventive risk management. Unintentional ingestion of water at undesignated recreational swimming sites may present public health risks. This study indicated that undesignated swimming sites were contaminated with enterococci as an indicator of faecal contamination (Jaravani et al., In review[c]). Most of these sites are located in the region's drinking water catchments.

Value of the practitioner-researcher approach

Practitioner-led research is a strategy that can be used as an adjunct to environmental health professional development and routine work (Nagykaldi et al., 2006). In our research work, value was added by regular meetings to promote continual interaction between stakeholders. Incorporating policy makers into the research process improved relevance of the research, increased research capacity of practitioners and policy makers, provided access to infrastructure, and facilitated linkage to policy. The evidence was translated by consensus into actionable outcomes which were disseminated through institutional reports to policy-makers; co-authored peer-reviewed publications; presentations at professional conferences; and partnerships and collaborations with other institutions, especially local governments. Thus, the evidence was readily adopted by both the policy-makers and practitioners as a Participatory Action Research outcome (Figure 2).

Figure 2: Participatory Action Research to close the gaps between research, policy, and practice (Personal expression).



A participatory action research model was intentionally adopted, rather than a prospective comparative model because it empowered participants to achieve a common goal and stimulated evidence ownership, making the translation of the evidence easier and timely (Thackway et al., 2017). Some of the policy and practice changes that occurred as a result of this body of research include:

- The engagement of policymakers ensured that the outcomes absorbed into statewide drinking water management programs in NSW rather than just the Hunter New England region. The research coincided with the statewide promotion of the development and implementation of drinking water quality assurance programs by the *NSW Public Health Act 2010* (NSW Government, 2010).
- Specific risk-based water management plans have been developed and implemented for each community to improve drinking water safety by the ADWG

(Byleveld et al., 2016). Risk-based drinking water assessment is a crucial component of the *Framework for Drinking Water Quality Management* (NHMRC, 2011), and the development of quality assurance plans is a legal requirement by the *NSW Public Health Act 2010 (*NSW Government, 2010).

- Customised Electronic Software for remote monitoring of Critical Control Points (CCPs) exceedances and recording of operational data into the central water databases have been initiated to enhance transmission of field data in real time understand and better manage the water supply systems the water supply systems. Most water supply systems are small and remote, with less frequent water quality verification tests (monthly). Remote monitoring will therefore improve operational monitoring of critical control points, which is more important in the provision of safe drinking water than verification monitoring.
- NSW Health has engaged specialist engineering contractors to assist small utilities to develop and implement drinking water management systems including targeted CCPs (Byleveld et al., 2016). Provision of safe drinking water is the responsibility of the utility. The literature indicates that the diseconomies of scale impact negatively on drinking water quality in small rural communities in NSW (Cretikos et al., 2010; Miles et al., 2011). Provision of government funded specialist water engineers will greatly help the small rural utilities to meet their obligations to provide safe drinking water.
- Risk-based quality assurance programs for private water suppliers are now mandatory. Both national and state recreational parks have developed and implemented risk-based quality assurance programs with scheduled electronic drinking water maintenance programs and water quality advisory notices (warning signs) by the *Public Health Act 2010* (NSW Government, 2010).
- The participation of the recreational park authorities and the PHU in the research process has enhanced close cooperation and working relationships. Advocacy for the adoption of the Beach Watch Program approach to inland swimming sites is continuing.
- State- wide Aboriginal community water management plans have been integrated into the local government utility drinking water management systems which are

reviewed regularly (Byleveld et al., 2016). The local utility is working cooperatively with the Public Health Unit, Local Aboriginal Land Council and the NSW Health. Office of Water to carry out feasibility studies and consultations for water softening to improve water palatability at the respective Aboriginal community. Programs that are informed, developed, led and governed by Aboriginal Peoples are more likely to succeed than imposed programs (Jamieson et al., 2012). Genuine, meaningful and respectful engagement and action that facilitates active and equal participation is critical in the development, implementation, interpretation of findings, and to the dissemination of any health program or research (NHMRC, 2003). Genuine partnerships can enhance interpretation of the feasibility study findings and exploration of further avenues to improve water palatability.

- Participation of the Aboriginal community has led to the boiling of rainwater before drinking to reduce potential disease outbreaks. Community participation in water sampling (in their houses) enhanced the translation of the evidence. The Local Aboriginal Land Council is considering scheduled rainwater tank cleaning. It is not government policy to promote drinking rainwater when reticulated water is available and the community understood that. Indigenous communities embrace working with researchers they can establish rapport with than unfamiliar researchers regardless of sophistication of amount of funds available (Jamieson et al., 2012). NSW Health and NSW Health. Office of Water are working with the community to treat town water hardness to make it more acceptable for the community.

Challenges of practitioner-led research

Given that environmental health is very practice- and policy-focused, bringing research into practice has significant challenges. Currently, environmental health practice in NSW is focused on enforcement of legislation, monitoring and reporting incident investigations with little practitioner-led collaborative research projects. Participatory action research is a rarity. The few practitioner-led research projects are rarely peer-reviewed. Research-practice partnerships remain elusive, and engagement of practitioner and policy end users by researchers has been reported to be often tokenistic even when such partnerships are incentivised with funding support (Wolfenden et al., 2017). Identifying and prioritising practitioner-led research projects was a big hurdle which required systematic and ongoing dialogue between the practitioner, academics and policy-makers. Carefully planned meetings and close collaboration with all stakeholders, taking into account administrative barriers, ethical and legal principles and the expertise of the various stakeholders was crucial for the success of the research project. Other challenges included the need for improved collaborations across disciplines and research infrastructure capacity, especially when competing with other practice and policy engagement priorities within the organisation.

Frequently, environmental health assessments produce ambiguous or questionable findings (Sharp, 2003). Communicating the ambiguities to policy makers, academics and the public is an enduring challenge for environmental health researchers impacting on the effectiveness of research translation into policy and practice. Explaining the inverse relationship between drinking water sampling adequacy and reduced *E. coli* detections is a good example (Jaravani et al., In review[a]). Continuous monitoring of critical control points and frequent sampling leads to early recognition of problems in the water delivery system such as high turbidity, low residual chlorine and infrastructure malfunctions, which can be readily corrected. Frequent sampling and the detection of *E. coli* are likely to result in increased awareness, informed vigilance, improved disinfection, reporting, governance, and improvements in the design and maintenance of infrastructure. As a consequence of frequent monitoring and system enhancements, water quality improves, and *E. coli* detections are reduced.

Time constraints including growing workloads, research confidence and expertise, and difficulties in arranging cover are recurring themes in practitioner-led research (Cook et al., 2002). “Becoming research-minded in this context is as much a process of identity construction as acquisition of competence” (Orme and Powell, 2007, p.16). The current situation suggests some degree of failure of environmental health practice to engage centres for higher learning in research training activities. The nucleus of any public health practice research process is the need to publish research findings for the public record. Publishing environmental health research findings in Australia is made difficult by lack of specialised environmental health journals, and particularly opportunities for communicating environmental health practice relevant research.

Lessons learned

Some lessons have been learnt that will inform future environmental health practitioner-led research. Confronting environmental health issues more often requires teamwork and systematic input from multiple disciplines who may not necessarily share working approaches particularly when there are no real or perceived threats to public health. Involvement of, and maintaining a close relationship with policymakers, practitioner-researcher and academics enhanced the status and adoption of research evidence resulting in more timely interventions.

The importance of balancing the demands of the workplace with research rigour is acknowledged. Practitioner research was nurtured within a learning set where academic experts, mentors and peers supported the projects Joint authorship in these cases seemed to reflect the supervisory or support role provided by academic researchers. Presentations and publication of peer-reviewed practitioners' research work enhanced both intra and inter-institutional relationships, improve research impact and encourage further research work to benefit public health practice and community outcomes. In this research work, there was close collaboration with local councils, government agencies and industry associations to promote awareness of the quality assurance program requirement for private water supplies and water carters (Byleveld et al., 2016).

Project leadership, organisational culture, and the desire for embedding research programs in current environmental health services were all important to the translation of research evidence to practice, and policy changes. A critical issue that facilitated the uptake of research evidence was that the research improved service delivery and was delivered using an interactive approach with decision makers. Continuous interaction and the cyclical nature of the projects led to greater chances of successful communication and adoption of evidence rather than a linear approach where the evidence is discussed and either adopted or rejected at the end of the project.

The PAR approach commonly revolves around a cycle of plan, act, observe, and reflect and advocate for change (DHHS, 2012; Kindon et al., 2007). In this research cycles were repeated in each project to allow the stakeholders to participate along the way, depending on the project context and the needs of clients, the broader community, and the specific conditions under which projects are delivered (DHHS, 2012; Kindon et al., 2007). Decisions on which research tools to use (e.g. meetings, workshops, surveys, interviews, focus groups) were determined in consultation with participants who decided how results would be utilised (Baum et al., 2006; Greene, 2006; Kindon et al., 2007). The practitioner-researcher primarily acted as knowledge broker, facilitating the interaction between knowledge producers (academics, researchers) and decision makers (management, policy makers and communities) (Tyler et al., 2019).

The research cycles required collaborative efforts to identify problems, collect evidence data and derive conclusions about how best to improve service delivery (Alston and Bowles, 2003; Owen, 2006). Responsibility for advocacy and change was not appropriated by the practitioner-researcher but considered to be a joint responsibility among participants and stakeholders. For example, round table workshops with utility management and staff, specialist water engineers and government representatives were held to brainstorm on barriers to meeting the provisions of the Australian Drinking Water Guidelines 2011. Brainstorming about causes and solutions and adopting ready to-use practical strategies from experience enhanced the adoption of the evidence (Gabbay and le May, 2004). The workshops resulted in the development and sustainable implementation of drinking water quality management systems for both public and private (Recreational parks) water supplies.

Learning that relates explicitly to the practitioner's daily work fosters opportunities for sustainable change to professional practice. In this research process it was learnt that the research cycle was not always sequential. Reflection and advocacy were imbedded in the cycle and enhanced the timeliness of research evidence adoption. Sampling adequacy was improved as soon as it became apparent that the utilities were non-compliant, and government assistance for drinking water quality management systems flowed before the end of the research process. Information on water quality and warning signs in the recreational parks were provided before the end of the project, the Aboriginal community began boiling rainwater before drinking after water tests showed high levels of *E. coli*, and a local government removed a flying fox colony in the upstream catchment of a swimming site immediately after test results showed high enterococci densities. While collaborative practitioner-research and advocacy might not be systematically implemented across NSW, it would appear that they were strongly endorsed in this research. The study provides an important insight into how context helps to encourage environmental health practitioner-research. Environmental health practitioners should utilise routinely collected datasets to generate evidence of effectiveness in the practice and use the data to consistently innovate and improve based on stakeholder feedback and practice evidence updates. The emergent lesson is that environmental health practice in NSW should adopt “a researcherly disposition” (Lingard and Renshaw, 2010) and engage academics as knowledge brokers between policy-makers and beneficiaries of the policy (Tyler et al., 2019).

Recommendations and Conclusion

Practitioner research is valuable and can be incorporated across public health practice especially in environmental health. Opportunities to bring research into or alongside routine environmental health work need to be explored in other settings to confirm its utility for catalysing evidence-based practitioner policy and practice changes.

These studies provide a firm foundation for environmental health practitioner-researchers to work with communities and policy makers to design future environmental health interventions for the translation of research evidence to policy decision outcomes, and public health practice leading to improved public health in rural areas. The outcomes of the practitioner–led research provides functional information to facilitate and strengthen inter-institutional sharing of experiences, use of research findings to improve cooperation among environmental health practitioners, water supply service decision-makers, and the communities they serve. The presence of common databases, such as the NSW Drinking Water Database, provide potential for undertaking research and policy interventions on environmental health determinants such as drinking water quality.

These positive relationships can be extended to other health protection programs and activities such as air quality, contaminated sites, food hygiene, tobacco control, skin penetration and legionella control. Ongoing community health programs can help to create meaningful relationships between Aboriginal communities, local Aboriginal health workers and public health practitioners. The resultant partnerships can then be employed to identify, investigate and explore possible solutions to the community environmental health problems.

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Chapter. 8 Overview, Main findings, Research Impacts, Recommendations for Future Research Directions and Conclusion

8.1 Overview

The creation of knowledge through research translated into policy and practice for public benefit promotes improvements in health service delivery and intervention (NHMRC, 2018). This research aimed to improve drinking water safety in regional areas of NSW, Australia by using environmental health practitioner research to narrow the gap between research, policy and practice. The primary approach was to use routinely collected environmental health data complemented by purposefully collected data, as evidence to support the implementation of improvements to drinking water management in rural New South Wales. The Hunter New England region in NSW was the setting for this research project. This research used the analysis of routinely collected drinking water quality data to identify areas for improvement. Also, this study was used to improve private drinking water management in the region and also to explore Aboriginal communities' perceptions of government supplied drinking water as a means to '*Close the Gap*' (Figure 8.1).

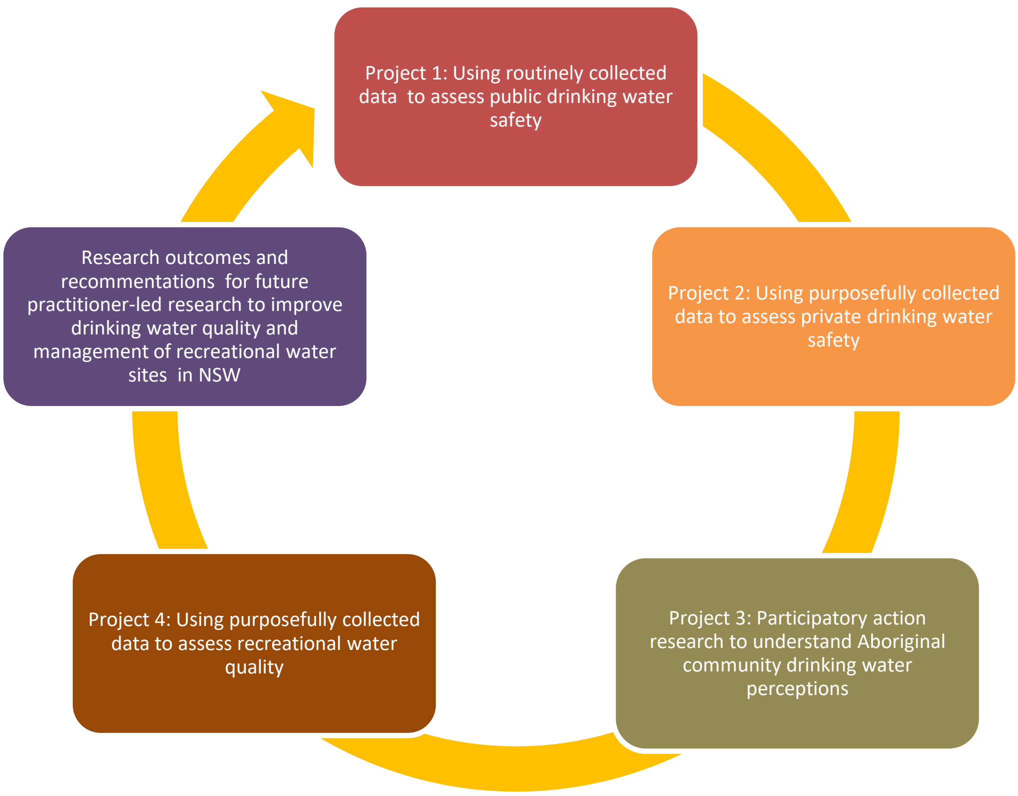

Figure 8.1 The research approach

The participatory action research process employed a mixed method approach. The research was based populating the cyclic participatory action research framework with practitioners, policymakers, academics, respective stakeholders and the community. This process helped shore-up support for policy change for improved public health. Engaged action research involves the identification of an issue, conceiving actions to address it, collecting data to assess its effectiveness and then reflecting upon the findings. This cycle is repeated to address emerging issues (Watkins and Noble, 2014). In this process, the practitioner was the link between researchers and policymakers, thus allowing the research idea to circulate throughout research, practitioner and policy networks. Practitioners, researchers, and policymakers shared common networks, trusted each other, and communicated regularly throughout the research period. Continuous interaction led to more opportunities for successful communication than a simple linear reporting approach (ODI, 2004). The interventions were based on identified community and public health needs and were designed to reduce public health risk and to enhance the success of the projects.

A critical outcome that facilitated the uptake of research evidence was that the participatory research process delivered solutions to problems and improved service delivery in an interactive process, with decision makers supported by academics (Balas and Boren, 2000). However, the disadvantages of practitioner-led research may include the inability of practitioners to critique their work adequately, their lack of skills in designing research questions, and that they are arguing against competing organisational and professional accountabilities (Fuller and Petch, 1995; Mitchell et al., 2008). Counterbalancing these disadvantages were the practitioner researcher's ongoing PhD training, the fact that he was working collaboratively with academics, policy makers and stakeholders from the point of planning of projects, ensuring that expectations were clear, the ongoing publication of outcomes in peer-reviewed journals and presentations at professional conferences. Working with expectations and outcomes upfront fostered adoption, translation and sustainability (Bartholomew et al., 2001).

The strategic objective of any drinking water utility is to provide safe drinking water to customers (NHMRC, 2011). The main focus of this research was water utilities' compliance with the NSW Drinking Water Monitoring Program (NSW Health, 2005), a derivative of the Australian Drinking Water Guidelines 2011 (NHMRC, 2011). The Program is required to ensure the taking of an adequate and a representative number of samples, at ample frequencies and appropriate locations in the distribution system that can monitor variability in the drinking water quality. Reported results from the NSW Drinking Water Database

(Database) are published in the annual NSW Water Supply and Sewerage Performance Monitoring Report (NSW Health, 2005; Water Research Australia, 2015; WaterNSW, 2017).

Risk assessment and management in the water supply is linked with the demonstration of due diligence (Miller et al., 2009). Due diligence includes the prevention of reasonably foreseeable harm through demonstrated evidence of a culture of compliance with set standards and commitment to preventive management, among other things. In Australia, the quality of drinking water is protected by the Framework for Management of Drinking Water Quality (Framework) as part of the Australian Drinking Water Guidelines (ADWG) (NHMRC, 2011).

In NSW, due diligence in the drinking water supply is tested through compliance with the NSW Drinking Water Monitoring Program (NSW Health, 2005). The program assists rural water supply authorities to monitor drinking water with free routine laboratory analyses of drinking water samples for microbial indicators and range of inorganic chemical and physical characteristics (NSW Health, 2005). The monitoring program encourages water utilities to implement the twelve elements of the Framework for Drinking Water Quality Management:

- Element 1: Commitment to drinking water quality management
- Element 2: Assessing drinking water supply system.
- Element 3: Preventive measures for drinking water quality management
- Element 4: Operational procedures and process control
- Element 5: Verifying drinking water quality.
- Element 6: Managing incidents and emergencies.
- Element 7: Employee awareness and training.
- Element 8: Community involvement and awareness
- Element 9: Research and development.
- Element 10: Documentation and reporting.
- Element 11: Evaluation and audit.
- Element 12: Review and continual improvement.

Monitoring serves as a check that barriers to contamination are working effectively, and utilities are exercising due diligence by using the multiple barrier approach from source to tap. Two types of monitoring are recommended. Water quality monitoring assesses the quality of water in the distribution system and as supplied to the consumer, compliance with the guidelines or agreed levels of service and as a trigger for corrective action to improve water quality. Operational monitoring confirms that the management processes and equipment to protect and enhance water quality are working efficiently. The information can be used as a trigger for immediate short-term corrective action to improve water quality, but not for assessing compliance with guidelines or agreed levels of service (NSW Health, 2005). Additional monitoring can also be required for emergency response to flooding or interruption of supply, monitoring of consumer satisfaction, research and reporting and accountability.

Detection of *E. coli* in a drinking water sample implies a breach in the elements and leads to thorough investigations to find out which Elements have been breached. Improvements to the management system and staff training to avoid repeat follows. NSW Health has developed a protocol for the response protocol for the management of microbiological quality of drinking water to assist in the response to *E. coli* and total coliform detection in a sample of water (NSW Health, 2018). The improvements in sampling adequacy and *E. coli* detections revealed in the current research show the water suppliers' progress in enhancing due diligence.

Source water protection and the operation and maintenance of robust water treatment processes are paramount activities in the effective protection of drinking water supplies from pathogens (NHMRC, 2011). Drinking water quality monitoring is a prerequisite for the verification of contamination barriers' performance and ensuring that consumers have safe drinking water (NSW Health, 2005; Water Research Australia, 2015). Regular sampling and testing of drinking water provide data on water quality, the efficiency of treatment systems and the integrity of distribution systems.

There have not been any reported public drinking water disease outbreaks in NSW. However, drinking water continues to pose a significant challenge to the public's health. The precautionary principle states that the decision maker must anticipate harm before it occurs and provide for some measure of protection against this harm, even if the probability cannot be determined accurately by the existing science (Crawford-Brown and Crawford-Brown, 2011). The precautionary principle encourages policies that protect human health and the environment in the face of uncertain risks (Kriebel et al., 2001). Gastrointestinal diseases are a leading cause of morbidity and mortality globally, and those most at risk are the most disadvantaged communities in rural areas.

Water quality can fluctuate rapidly, and all systems are subject to occasional failure (WHO, 2011). Under section 61 of the *NSW Local Government Act, 1993*, the NSW Health. Office of Water carries out regular inspections of the water treatment works and provides feedback and mentoring to the water utilities. Sampling locations and frequency are scheduled using page 206 of the 2010-11 NSW Water Supply and Sewerage Benchmarking Report (Samra and Mclean, 2012) and the Australian Drinking Water Guidelines 2011 (ADWG) (NHMRC, 2011). The reliance of regulatory structures on compliance monitoring of treated water tends to promote a reactive management style (Sinclair and Rizak, 2004). Corrective actions occur after monitoring reveals that prescribed levels have been exceeded, and generally after consumers have received the noncomplying water. There is a widespread tendency to assume that intensification of compliance monitoring is an effective strategy towards improving the protection of public health.

The Chief Health Officer has the power, under Section 22 of the *NSW Public Health Act 2010* (NSW Government, 2010), to issue advice, for the benefit of the public, concerning the safety of available drinking water and any possible risks to health involved in the consumption of that water (Byleveld et al., 2008). Such advice considers:

- Detected levels of contamination;
- Effectiveness of current disinfection (and whether organisms may be viable);
- Likelihood of identification and correction of the problem (i.e. consider findings of contamination investigation and sanitary survey);
- Time and scale of exposure including the likely recency of the contamination (when were people exposed? are they still exposed?
- The number of people exposed;
- Evidence of illness (or complaints about the quality of water) in the present or previous events;
- Community exposure;
- The need to communicate accurate and appropriate information to the community in a timely and effective way; and
- Impact of any public health action (Byleveld et al., 2008).

Routine drinking water monitoring, frequency analysis of the data by the water suppliers and environmental health practitioners from the Public Health Units and reporting the results enables the Chief Health Officer to perform these functions diligently.

Geography is the defining characteristic of rural NSW, but rural areas are also economically, sociologically and culturally different from metropolitan areas (Wakerman and Humphreys, 2002). In NSW, rural communities usually manage their drinking water through the local government council, whereas in metropolitan cities, specialised utility corporations are responsible (Byleveld et al., 2016). Substantiating evidence to reduce the risk and impact of drinking waterborne diseases in rural areas will contribute to reducing the metropolitan/rural health divide. It is, however, the obligation of water utilities to provide safe drinking water to all consumers (Charrois, 2010; Byleveld et al., 2016).

8.2 Main Findings

8.2.1 Summary of findings

- Use of routinely collected data can contribute to research and to improve practice. Routine verification of monitoring data provides valuable information on potential problems that may not be apparent during performance monitoring. Such data highlights deficiencies that can be used to inform continual improvement processes. Economists use the term “probe and learn” to explain the use of data to teach that the generation of error is part of a productive learning process that should not be suppressed because it is an essential indicator of success (Cole, 2002).
- Sampling adequacy improved (t = 32.40, [95% CI 88.61-94.47], p=0.000 Wilcoxon T-test for Trend) (Jaravani et al. In review[a]). The highlighting of the deficiencies in sampling adequacy, roundtable workshops and assisted development and implementation of drinking water quality management plans compelled utilities to improve their verification monitoring. Verification monitoring of water quality is one of the components of the guidelines framework elements.
- *E. coli* detection improved (t = 4.38 [95% CI 0.88-2.56], p = 0.001 Wilcoxon T-test for Trend) (Jaravani et al. In review[a]). The data on *E coli* detections was correlated to the sampling adequacy (Jaravani et al., In review[a]). Absence of *E. coli* verifies the efficiency of the multi-barrier approach to safe drinking water including source water protection, water treatment, water disinfection, distribution system integrity and operational monitoring.
- Smaller communities have greater exposure to drinking water risks than larger communities. Sampling adequacy was significantly lower (IRR = 0.83 [95% CI 0.70-1.00], p=<0.036) and *E. coli* detections were higher (IRR 4.25 [95% CI 1.37-13.20], p=0.0123) in smaller than in larger communities. Long distances to the sampling sites, low CCP performance monitoring were the main causes of the discrepancies. Safeguarding water quality in small communities is a global challenge (Dos et al., 2007) and can be controlled by maintaining the integrity of the supply system CCPs and stringent operational monitoring (NHMRC, 2011).
- Cooperatively working with recreational parks, water suppliers have improved drinking water safety. Regardless of the overall policy to declare water supplies in the national parks non-potable, round table meetings with the managers resulted in the development of a generic quality assurance plan and provision of water quality

advisory notice (warning signs) at all water points. The State parks have opted for specific quality assurance plans for each recreational park with water quality information when the water was not potable.

- Aboriginal communities prefer untreated rainwater to town water. From the findings, town water hardness was the primary influence for people preferring rainwater. The perception of harm from water hardness and taste has led to the parents discouraging their children from drinking the water.
- Transgenerational influence is an important factor in drinking water perception in Indigenous communities. The transgenerational influence and strong kinship have led to the community's decision not to drink the town water regardless of the knowledge that it is microbiological safer than the rainwater.
- Early engagement and collaboration with Indigenous communities improved trust and helped to build long term relationships. Before engaging with the community about their water issues, the practitioner-researcher's previous work with the community supported the researcher to gain insights into the community's needs and cultural perspectives. Working with the community gave community members an active voice defining the problem, and to map the way for possible solutions, and helped in the collection, adoption and translation of the evidence.
- Recreational swimming sites had high Enterococci densities. This outcome was expected because there no water management strategies in place in most of the swimming sites. The 2008 Australian Guidelines for Managing Risks in Recreational Water recommend regular monitoring (NHMRC, 2008).
- Engagement of policy-makers, stakeholders and academics reduces the gap between research and policy. The collaborative participation of decision-makers, academics and other stakeholders in the four projects are responsible for the positive outcomes of this investigation. These outcomes occurred over the five years of the research project. The sustainability of the research outcomes is evidenced by the continued funding of the implementation of drinking water quality management systems by the NSW Health regardless of the size of the utility. Collaborative discussions with private water suppliers also continue.

8.2.2 Summary of outcomes

The main outcomes of this research were:

- Reviews of drinking water supply performance, including the development and implementation of drinking water quality assurance plans. NSW has invested in contract specialist water engineers to work cooperatively with the utilities, the public health unit and the NSW Office of Water to review the operational performance of water supply systems, expressly identifying hazards and critical control points (Byleveld et al., 2016).

- Development of scheduled system maintenance. The specialist water engineers have assisted the small water utilities to identify defects in the infrastructure, particularly the treatment regimens, and the distribution reservoirs integrity; developed routine operational procedures; and trained the operators on maintenance monitoring for the integrity of the systems. *E. coli* detection data helped to identify any systems that required more attention.
- Installation of continuous online, operational monitoring of Critical Control Points and improved verification testing the water quality. The sampling adequacy, *E. coli* detection data and risk assessments helped the water engineers, utilities and the public health unit to identify water supply systems that required more consistent operational monitoring. Such systems were often small and were only visited at most once a week due to distance from the offices and operator shortage had monthly sampling frequencies. Therefore online performance monitoring targeting critical control points were recommended. Utilities have improved on sampling adequacy to comply with their drinking water management systems' requirement for regular verification monitoring by the NSW Drinking Water Monitoring Program allocated sample numbers and sampling frequency.
- Development of disinfection optimisation strategies, including disinfectant Contact-time (C.t) factors for the public drinking water supply systems to achieve a minimum of 0.2 mg/L free residual chlorine in the distribution system. To calculate the C.t for a drinking water scheme, the volume of storage at the lowest normal operating water level, peak flow rate, baffle factor, target free chlorine residual at first customer point are required. Caution should be used in applying C.t values to disinfection practice in the field because laboratory data obtained under ideal conditions do not always relate to field conditions Australian Drinking Water Guidelines (ADWG) (NHMRC, 2011). Generally, in clean water, a residual chlorine level of 0.5 mg/L after a contact time of 30 minutes should be sufficient to ensure microbial control, given a clean distribution system and no significant recontamination, and suggests that a minimum C.t of 15 mg.min/L is required (NHMRC', 2011).
- This work has seen significant reductions *E. coli* detections in the 66 supply systems in the region. The development and implementation of drinking water management systems including risk and critical control points identification,

infrastructure scheduled maintenance, calculation of C.t and online, operational monitoring for small drinking water systems have helped to maintain the water quality. The improved sampling frequency assures that the systems are more regularly verified for compliance with the management systems by the NSW Drinking Water Monitoring Program.

- Review of the NSW Drinking water database to include performance monitoring data. Reporting water quality consists of the internal and external reporting of activities pertinent to drinking water quality management (NHMRC, 2011). Internal reporting supports decision making and provides means of communicating information on decisions within the organisation. Regular external reporting ensures that drinking water quality management is open and transparent. NSW Health has upgraded the drinking water database to include reported data on operational monitoring to monitor operational compliance with critical control points. Utilities voluntarily provide the data. The public health unit regularly inspects operational data for utilities that do not provide the data to NSW Health. Water utilities must immediately notify the local Public Health Unit of any incident affecting the ability to provide safe drinking water and take actions responding to critical limit exceedances, raw water quality problems, reservoir contamination and test results indicating possible contamination. The PHU can support and advise the water utility on its investigation and response.
- Regulatory changes have been implemented to improve drinking water sampling adequacy, microbiological quality and public warnings about water quality in rural NSW, including private drinking water supplies. This research coincided with the new provisions of the *NSW Public Health Act 2010,* and the NSW Public Health Regulation 2012 that require utilities to develop and implement drinking water management systems (quality assurance programs). Private water suppliers are defined and included in the Act and regulation. The laws have been amended to include penalties for noncompliance. NSW Health has worked cooperatively with the water industry, local governments, and the NSW Office of Water to educate water suppliers on requirements of the legislation. NSW Health and NSW Office of water have developed documents to assist suppliers in meeting their legal obligations: Assuring the safety of drinking water supplies. Circular Number LWU 18 (Office of Water, 2014) and NSW Guidelines for Drinking Water Management Systems NSW Health (Office of Water, 2013). The NSW Private Water Guidelines have also been updated to assist private water suppliers to comply with the additional provisions of the legislation. Crown Lands (State Parks) and National Parks and Wildlife Service have led the way in implementing these provisions of the

legislation and guidelines as participants in this research. The Public Health Unit is working with private water suppliers and water carters to develop and implement quality assurance programs.

- Softening of town water at a discrete Aboriginal community to improve palatability. The studied Aboriginal community preferred untreated rainwater to the regularly monitored reticulated water supply because of the water hardness and taste. Parents discourage their children from drinking the reticulated water. The project has encouraged the community to boil the rainwater before drinking. Some community members have indicated a willingness to drink the reticulated water if the hardness is treated. The NSW Office of Water has agreed to fund the softening of the water under the Aboriginal Water and Sewage Program. The local utility which supplies bulk water to the community is undertaking a feasibility study for water softening. Research participants and the researchers strongly believed that more community members would drink the water if they are involved in the feasibility study and effects of hardness such as clogging of electrical gadgets and shower roses and improvement in soap lather are observed. The participation of the Local Aboriginal Land Council in the research study promoted the translation of the research evidence and made the advocacy easier.
- Advocacy for the management of popular informal swimming sites and regular warning to swimmers about water quality similar to the Beach Watch Program has been initiated. The popular coastal swimming sites in NSW are regularly monitored for water quality under the Beach Watch Program. Swimmers can make informed decisions before swimming. This research program has advocated for similar monitoring for rural popular swimming sites along major rivers and at dams.

8.2.2.1 Public drinking water safety (Project 1)

The use of routinely collected data as a research resource has encouraged NSW Health's recognition of the importance of supporting and funding regional utilities, especially those with limited engineering expertise and financial capacity to develop, implement and continually improve risk-based drinking water management systems. These management systems include targeted Critical Control Points (CCPs), required by the *NSW Public Health Act 2010* (Byleveld et al., 2016).

Customised Electronic Software for remote operational monitoring of Critical Control Points (CCPs), exceedances and recording of operational data into the central water databases, have been employed to enhance transmission of field data in real time, to understand and better manage the water supply systems. Annual reviews of drinking water management systems enable the assessment of water quality on annual yearly basis by the water utility and the Public Health Unit, for the benefit of system improvements and public health in the medium term. The analysis of the database for the whole region should be synchronised statewide and be used to improve the program in the long term as an essential stage in the program.

The occasional detection of *E. coli* in drinking water suggests inadequate treatment, disinfection, regrowth or infiltration in a water distribution system. However, detection of *E. coli* in a water sample does not necessarily mean that the water is unsafe, as *E. coli* may be detected in systems that are operating efficiently (NHMRC, 2011). The detection should trigger an immediate investigation to ensure that treatment, disinfection, and the reticulation system have not been compromised. Data obtained from a comprehensive monitoring program may identify parts of the water supply system in need of maintenance or upgrade, (NSW Health, 2005) and guide reviews of drinking water management systems (Byleveld et al., 2016).

8.2.2.2 Drinking water safety in recreational parks (Project 2)

Routinely evaluating private water supply quality parameters enables private suppliers to be aware of potential problems with their water supplies and to use appropriate management strategies. Disparities between private water supplies and the absence of consistent policies and programs to support private water supply systems have been addressed. Quality assurance programs have been shared to provide examples for other private suppliers, including caravan parks, bed and breakfast facilities, guest and road houses and water carters.

The NSW Private Water Supply Guidelines have been amended to include mandatory drinking water quality assurance programs. NSW Health has published updated NSW Private Water Supply Guidelines (NSW Health, 2014) and NSW Guidelines for Water Carters (NSW Health, 2012), water treatment fact sheets, and quality assurance program templates that can be adapted for different water supplies.

8.2.2.3 Drinking water safety in Aboriginal communities (Project 3)

This research presents important insights that water supply authorities need to consider when assessing health risks, choosing appropriate mitigation measures, and building business cases for water quality improvement programs in Aboriginal communities. These programs should involve communities in the process and address community social concerns about town water supplies. Only Aboriginal people know what is best for Aboriginal communities. Through this study, the community now is aware that town water is safer than rainwater. We contend that if the town water is softened, and children are allowed to choose, with time there may be a generational change and the uptake of safer town water will increase.

Each Aboriginal community is unique. The findings of this research may not apply to other Aboriginal communities, but community engagement can bring a wide range of benefits if the process is flexible. Active participation of community members and ownership ensured that the program was responsive to community needs, conducted in a culturally appropriate manner, and was beneficial to the community. Researchers can bring their professional skills and what they have heard or read about a community to the table, but community members bring what they have experienced and know. Ongoing community health programs can help to create a meaningful relationship between Aboriginal communities, local Aboriginal health workers and public health practitioners. The resultant partnership can then be employed to identify, investigate and explore possible solutions to the community drinking water problems.

8.2.2.4 Recreational swimming sites microbial safety (Project 4)

Despite the safety of drinking water supplies, consumers may get gastrointestinal infections from informal swimming sites. There is a need for risk-based water quality management at informal recreational swimming sites in the region. Work with local governments in NSW is underway to initiate the management of popular informal swimming sites and to regularly warn swimmers about water quality, like the Beach Watch Program.

8.3 Significance of the Research

The projects were carried out locally with the participation of the respective managers and users. Participants were comfortable with the information that related directly to their practice experience and work, including local data and personal experience. PAR requires evidence (or data) that is timely, relevant to the context and purpose, current, and translated into manageable actions. Participants need pertinent projects relevant to the local context to realise the return on investment of information and effort applied (Tyler et al., 2019). The relationship between problems, solutions and practice enfolds and embraces the whole cyclical process of action research at every stage. Efforts within this research were focused on increasing collaborative work with diverse stakeholders through networking, attending service and agency meetings and inviting representatives to participate in internal meetings.

This research has yielded some significant outcomes. The engagement of policymakers throughout these studies ensured that the results were implemented not just in the Hunter New England Region but more broadly throughout NSW in conjunction with other State drinking water management programs. Policymakers are important players who know the kind of evidence that is needed in an organisation and how to drive its use (Williamson, 2019). Participation of academic researchers as advisors to the practitioner-researcher helped to synthesise the research evidence and gave confidence for engaging stakeholders with this evidence. Academic researchers acted as knowledge brokers, facilitating the interactions between practitioners, policymakers and evidence beneficiaries (Tyler et al., 2019). Knowledge brokering has been reported to enable evidence familiarity and manageability, increase user confidence in using the evidence and increase the likelihood of evidence use (Tyler et al., 2019).

Environmental health practitioner-led research fostered self-reflection and better understanding of practice by researchers. This occurred by researchers actively assessing their own practice, and practitioners were empowered by improved professional recognition. This process inspired more participatory actions to produce evidence for policy changes. The ever-emerging demands and competition from other health protection fields inspired an urgent effort to link practice and practitioner-led research from a wide range of stakeholders, including academic researchers and policy-makers, in order to improve practice to match demands. Environmental health practitioners need to continually develop the knowledge-base on drinking water hazards and emerging issues, new water treatment and data analytical methodologies and the relationship between water quality and health outcomes.

Six journal articles and four presentations at professional conferences provided opportunities to promote the integration of research into practice and work to effect policy change to improve the professional for public health benefit. Significant changes to policy and practice at the local and state level have resulted from this research. The research has provided the water utilities, local Public Health Unit and NSW Health opportunities to review sampling adequacy and improve water safety in the region and state-wide respectively.

State wide Guidelines for Drinking Water Management Systems have been developed to assist water utilities to continually improve on drinking water quality management (NSW Health, 2013). Annual reviews and four yearly external audits of the management systems are now a requirement for each utility to review the continual effectiveness of the management systems. These reviews particularly address the performance of CCPs, water quality data and levels of service as measured by consumer complaints, and provide for continual improvement. The NSW Drinking Water Database has been improved to address the deficiencies identified during the data processing stage of the research, thereby improving the efficiency of the Drinking Water Monitoring Program.

The participation of the recreational parks authorities in the research and application of the evidence has enhanced closer cooperation and working relationships between NSW Health and local councils, government agencies and industry associations. This cooperation has promoted awareness of the drinking water quality assurance program requirement for private water supplies and water carters state-wide (Byleveld et al., 2016). The provision of monitoring and sampling results acted as an incentive to parks authorities, as private water suppliers, to improve risk management strategies. A broader review of water management policy by the NSW National Parks and Wildlife Service (NPWS) has been initiated. The implementation of preventive risk management approaches through the development of quality assurance programs, including water quality warning signs, operational procedures, monitoring, corrective action plans and continual improvement strategies for recreational parks state wide has been strongly endorsed. Two dam supplies were upgraded, with one adding filtration to support UV light disinfection and the other installing UV light disinfection. The improvements initiated will undoubtedly improve drinking water quality in the recreational parks in northern NSW.

In response to this study, the feasibility of installing a water softener at Walhallow is under consideration. The Community is engaging with the private sector to improve rainwater management. This outcome presents valuable insights that water supply authorities need to consider when assessing health risks: choosing appropriate mitigation measures and building business cases for water quality improvement programs at Walhallow. The findings can inform potential interventions to improve drinking water quality in Aboriginal communities by encouraging the involvement of communities in the process and by addressing community social concerns about town water supplies. Tangible improvements in the quality of town water will not be fully utilised if the community is distrustful about the supply. Understanding this outcome can improve future programs and policies for the supply of adequate and acceptable drinking water to Aboriginal communities.

Participatory action research is a culturally appropriate approach for working with Aboriginal communities in order to create a joint research outcome, and it can be applied in and with other Aboriginal communities in NSW and Australia. Early engagement and collaboration with Indigenous Communities improved trust and helped to further long-term relationships in the current project. The research has stimulated the development of concepts such as relational continuity (Kristjansson et al., 2013), working alliance (Fuertes et al., 2007), and relationship-based service (Shellner, 2007) in the area of public water management research. The concepts describe the positive outcomes that result when participants have a sense of collaboration, association and trust in the research evidence application and ownership.

8.4 Recommendations and Future Research Opportunities

Despite the success of the project, further research on several issues is needed to further improve drinking water quality in rural areas of New South Wales and Australia.

8.4.1 Determining water sampling frequency

The number of drinking water samples allocated by the Australian Guidelines (NSW Health, 2005) is based on the population served and the complexity of the system. Small systems that analyse less than one sample per week for indicator bacteria have a low degree of statistical confidence that the supplies are free from contamination at all times, even with high sampling adequacy and low *E. coli* detections (NSW Health, 2005). To achieve 98% of samples with nil *E. coli* detection annually, small supply systems would need zero detection per year. We recommend that the projects be carried out in small rural communities to determine the seasonality of water contamination and encourage the redistribution of sampling numbers to reflect the seasonality of *E. coli* detections. The ADWG recommend a minimum of one microbial sample per week (NHMRC, 2011). However, the guidelines note that in small systems this is not always practical. Where sampling is less frequent than recommended, sanitary inspections should be more frequent, to assure the integrity and efficient operation of the system.

The projects would determine the source water quality, treatment regime (microbial log removal value), and operational monitoring data (CCP exceedances as proof of performance monitoring). These would be coupled with the compliance monitoring data (e.g. *E. coli* detection rates) and seasonality of water contamination events. There is need to develop and trial an index system to inform sampling frequency that is not only based on population and complexity of the supply system but includes public health risk.

Small supply systems that detect *E. coli* more often need to implement stringent operational monitoring systems coupled with more frequent verification testing. NSW Health and the respective local utilities (Local government) can work together to lobby for or find ways of funding the required extra operational monitoring systems and verification testing, especially during emergency situations like flooding and severe prolonged droughts. Strengthening water safety management includes increased reliance on audit-based surveillance in small water supplies, and stringent implementation application of DWMS to mitigate water quality risks (Lloyd and Bartram, 1991; Rahman et al., 2011; WHO, 2011b).

Alternatively, utilities may maintain the allocated sample regimes, but smaller supply systems may be afforded portable on-site field-testing equipment for testing disinfectant residual and turbidity in the distribution system. This monitoring would complement the recently introduced online turbidity and chlorine residual tests and verification monitoring sample allocations. Field tests for indicator microorganisms, such as total coliforms and *E. coli*, are making such tests feasible as part of drinking water quality monitoring in small and remote locations where it may not be possible to get samples to laboratories within the timeframe required for accurate analysis, or the costs of doing so are prohibitive (NHMRC, 2011 pp. 151). Field tests may lack in precision and reliability and need to be balanced against the benefits of the increased frequency of monitoring that is possible. Operators should understand the operation of monitoring equipment so that causes of spurious results can be recognised and rectified (NHMRC, 2011). It is essential that operators are appropriately trained, analyser kits are calibrated as per the manufacturers' specifications, and that an audited quality assurance program, including proficiency testing, is incorporated to monitor testing performance. However, such field tests should never substitute strict adherence to the source-to-tap approach to drinking water quality management. It is essential to maintain effective barriers to faecal contamination, given the limitations in the ability of indicators to predict health risk accurately.

When the monitoring program aims to compare test data against guidelines, it is important to sample often in order to note the possibly brief occasions when the guidelines are exceeded (Australian and New Zealand Environment and Conservation Council, 2000). Global efforts have focused on the development of appropriate testing methods for low-resource settings (Bain et al., 2012; Rahman et al., 2010; Stauber et al., 2012). Use of disposable test kits would be preferred, in order to avoid the false positives due to poor handling of the reusable equipment. Peletz et al. (2018) argue that limited influences of equipment and infrastructure on monitoring performance may reflect the abilities of motivated water quality managers to address practical constraints by relying on portable testing kits. Such kits may also be valuable to private water suppliers such as recreational and holiday parks not in the NSW Drinking Water Monitoring Program, who are not provided with the free routine testing service.

It is imperative for utilities, researchers and policy makers to select water quality tests appropriate for a given setting and application (Bain et al., 2012). The effectiveness of these kits would depend on the understanding of the institutional characteristics that influence water quality monitoring performance (Peletz et al., 2018). If the purpose of testing is to ascertain the presence or absence of indictor microbes, onsite tests may be adequate as long as the volume is sufficient and the test has the necessary validation and approvals (Bain et al., 2012). Presence/Absence tests are also valuable when monitoring water supplies that are usually free of contamination. The resulting string of “non-detects” or infrequent positives gives more confidence than a single quantitative test (Bain et al., 2012; Clark, 1968). However, if there is a need for relative prioritization (e.g., resample after *E. coli* detections) or there is a reasonable risk of contamination, a standard quantitative test will generally be required. For operational monitoring this decision should be based on an understanding of the likely levels of contamination in the sources being assessed.

Utility plant operators would need formal and preferably accredited training on all the unit processes employed at their plants, in order that they can understand the purpose of water sampling, and can improve their sampling procedures. Training to a level of technical competence appropriate for the risk at a particular plant is essential for appropriate drinking water monitoring (Water Research Australia, 2015). However, applicability, supervision and quality assurance auditing would be paramount, considering the conditions under which the on-site testing would take place and the unspecialised nature of the responsible operating staff (Lahey, 2005). The WHO Guidelines for Drinking Water Quality provides a checklist for effective analytical quality assurance (WHO, 2011b). The data collected would be assessed both in the short term and over time to determine both immediate actions required and any trends that may be emerging (Ministry of Health, 2007).

8.4.2 Critical Control Points (CCP)

The required sampling rate may be too infrequent to capture short-term contaminant variability in the drinking water (CEHTP, 2015). Currently, in NSW, pathogens cannot be measured by on-line analysis. Laboratory testing for indicator *E. coli* is a relatively slow process, which makes it only suitable as a verification monitoring exercise, and not suitable for operational process monitoring, especially for small supplies with only a few allocated samples per month. Therefore, the best way to ensure the production of microbial safe drinking water is to encourage strict operational monitoring performance for each process contamination barrier. Critical control points are the nucleus of the Australian Drinking Water Guidelines Framework. The ADWG recommends the use of online turbidimeters on each water filter. Records of CCP exceedances and their causes would help in assessing and determining the contamination risks likely to be encountered in each drinking water supply system. Such records can then be used to determine the annual verification sample allocations depending on the risks.

Operational monitoring verifies the effectiveness of treatment and distribution processes and guides corrective actions. The Australian Drinking Water Guidelines specify some critical limits for safe drinking water (NHMRC, 2011). Failure to adhere to the critical limits indicates the failure of the critical control points and failure to provide safe water. However, small rural water supply systems may not be able to adequately monitor the critical limits specified in the guideline, due to diseconomies of scale which may result in failure to provide safe water. The advantage of the guideline Framework is that it emphasises the preventive approach to managing water quality, with less reliance on water testing. The Public Health Unit can utilise treatment plant operational monitoring data to assist such small systems in establishing appropriate critical control limits and standard operational procedures. The Public Health Unit continues to work with utilities to investigate any non-compliant samples and assess the health risk to the community and advocate for improvements to mitigate the risks.

8.4.3 Consumer perceptions

Research has tested NSW regional water supply systems for compliance and regulatory purposes, not for health tracking (Cretikos et al., 2010, Jaravani et al., In review[a]). The work with an Aboriginal community indicated that some communities may not be adequately utilising the service and that it is necessary to assess the proportion of community members who use the drinking water facility compared to those who do not (Jaravani et al., 2017). Individual behaviours (consumption of tap water, bathing and use of bottled water) may influence exposure, complicating efforts to estimate cost effectiveness of a water supply system (CEHTP, 2015). It may not be cost effective to treat and maintain the water when it is not being consumed.

A major research priority is the assessment of the use and acceptance of town water supplies in multiple rural NSW rural communities (Jaravani et al., 2017). A cost-benefit study could develop better understandings about whether the resources expended in maintaining the town water supplies are worthwhile and cost effective. The findings can inform potential interventions to improve drinking water quality in Aboriginal communities by involving communities in the process and by addressing community social concerns about town water supplies. Programmed interventions are unlikely to fully achieve the intended benefits without a good understanding of the social factors influencing drinking water choices. They will achieve better results by incorporating appropriate and adequate responses in partnership with communities involved to mitigate such factors (Jaravani et al., 2017).

Participatory approaches to encourage consumer engagement, provide continual education and supply information materials designed to address key risk and trust factors known to influence customer perceptions of drinking water quality will help to encourage consumers to consume water of safe water of known quality. The current research recommends the utilisation of system dynamics (Currie et al., 2018; Diez Roux, 2011) coupled with programmed work. It is worthwhile to seek explanations for community behaviour by understanding the internal structure of the community rather than by focusing on factors external to the community (Currie et al., 2018). It is tempting to blame culture and the history behind community beliefs for the reason behind communities' preference for untreated rainwater over treated and routinely monitored town water. An endogenous view may assert that preferences are the result of a combination of systemic factors such as the aesthetic qualities of the water supply (taste, smell, and hardness), community knowledge about the risk of alternative sources and community involvement in the supply chain. Using this logic, the solution would lie in understanding how these factors combine with cultural and historical factors and consequently modify the system to encourage communities to consume safer water. The close working relationships and cooperation between this community and the Public Health Unit has been strengthened. This positive relationship may be extended to other health promotion programs and activities in the future.

8.4.4 Research capacity building

Environmental health policies and programs are best guided by evidence-informed approaches to increase the successful implementation of programs and policies (Brownson et al., 2009). The NSW Ministry of Health has commissioned a rapid review to identify strategies, including research literacy that foster the use of research in population health policy and programs (Moore et al., 2009). Managers should be encouraged to participate in research projects in order to improve their relevance and encourage stronger links between research, policy and practice. The involvement of managers in research has been found to improve research relevance, validity and credibility, through better understanding of research processes (Bullock et al., 2012). Research evidence-informed environmental health practice should form part of the organisational culture through reviews of routinely collected data.

There is a need for an organised scheme for presenting environmental health research findings to managers and practitioner networks. "*What gets measured, gets changed.*" (Chriqui et al., 2011). Interrogating routinely collected field data and sharing it with management may have the most impact on practice and policy change. The scheme could include interactive seminars, workshops, conferences and peer reviewed publications to build research development capacity, professional and stakeholder collaborations, disseminate what is learned and facilitate research evidence implementation. Environmental health interventions often require multidisciplinary approaches, hence multiple perspectives from diverse groups including policy makers, managers, practitioners, academics and the community must be considered in the decision-making process. Such interventions would consolidate policies and develop practices that are motivated by the best available evidence and knowledge.

This research project has exposed me to the four stages of the learning cycle:

- **Concrete Experience:** I have enhanced my experience-based learning in practitioner-led research, experienced the different levels of influence and varying interests of stakeholders involved in water safety management research in real-life context in the four projects;
- **Reflective Observation:** I have reflected on the challenges, met with the stakeholders and discussed the way forward, demonstrating the significance of effective stakeholder engagement and collaboration in decision making on drinking water quality;
- **Conceptualisation:** I used the solutions to the challenges as learning objectives to strengthen my decision-making processes to achieve public health outcomes; and
- **Active experimentation:** I can now practice the concept of practitioner-led research in real-life situations with professionals, academics, policy-makers and communities with divergent ethical and legal, scientific, technical, socio-political and cultural attributes. (Ferrero et al., 2018; Kolb, 1984).

8.5 Limitations of the Research Project

The current research did not investigate the detection rate of total coliforms in the Hunter New England, even though routinely collected data is readily available. In NSW all drinking water monitoring program microbial tests routinely provide *E. coli* and total coliforms. Total coliforms should generally not be detected in water sampled immediately after disinfection. Regardless of the failings of total coliforms to indicate health risk from enteric bacterial pathogens, they provide essential information on water management process efficiency which is important for health protection (Ashbolt et al., 2001). Total coliforms can be used as a systems indicator to provide information on the efficiency of water quality management (APHA 1995). Presence of total coliforms may suggest regrowth or possible ingress of foreign material which may point to the presence of opportunistic microbes such as *Klebsiella* and *Enterobacter,* which can be found in nutrient-rich water and decaying vegetation and can multiply in water environments (Pinfold, 1990; Ramteke et al., 1992; WHO, 2011a). Pathogenic bacteria such as *Shigella spp, V. cholera, Campylobacter and Yersinia* may also be indicated (Grabow, 1996).

No ADWG value has been set for total coliforms in drinking water. As an indicator for disinfection residual, the test for total coliforms is less reliable than direct measurement of disinfectant residual (NHMRC, 2011). If used as an indicator for environmental contamination, numbers should be established on a system-specific basis, and increased concentrations should be investigated (NHMRC, 2011 pp.274) including system characteristics and historical data (NSW Health, 2005). The presence of total coliforms in the absence of *E. coli* does not necessarily indicate faecal contamination or enteric pathogens. However, increased detection of total coliforms in drinking water samples may raise suspicion of treatment failure or contamination with non-faecal material. The NSW Drinking Water Monitoring Program provides a protocol for the detection of total coliforms, suggesting that if detected, water utilities should check that the disinfectant concentration is adequate, and that operation of the treatment plant and delivery system is normal. Water utilities may set system specific targets for total coliform bacteria (NSW Health, 2005 p. 20). The revised US EPA Coliform Rule has removed the standard for total coliforms (US EPA, 2013, Edberg, 2015). Some fecal and non-fecal pathogens including *Legionella*, *Mycobacterium avium* complex, *Pseudomonas aeruginosa*, poliovirus 1, *Coxsackievirus B* have been established as part of biofilms and can be protected from disinfection (Provost, 2012).

Determination of coliforms in drinking water due to biofilm is ordinarily a negative conclusion, i.e. there is no apparent contamination of the water works system, no identified breakdown in treatment barriers or no apparent cross-connection with untreated water (Lahey, 2005). The onus should be on the utility to show that such coliform occurrences are a result of biofilm release into the water supply. We recommend further studies to verify that the total number of coliform detections reported in the NSW Drinking Water Database were from biofilms, and whether the recommended response protocol is strictly adhered to for such detections. It may be practical to determine the causes of the biofilms and the release of the coliforms.

The study on recreational parks drinking water quality only assessed water provision in governmental recreational parks most of which were declared non-potable although the actual intent of the water supplies was not always spelt out for the benefit of visitors. The majority of the assessed sites did not provide treated and regularly monitored water. Such parks cannot be considered to represent private water supply quality in the region. Assessing risks in privately owned recreational parks could have added value to the project. However, it was considered that the most privately-owned parks have built up caravan parks and provide food. Such facilities are mostly run on commercial basis and are monitored by the local governments according to the *NSW Food Act* 2003 or the *NSW Local Government Act* 1993 (NSW Government, 1993, 2003).

Only one community was used to assess Aboriginal perceptions of reticulated drinking water supply. A cross sectional study across the region and comparison with other discrete and integrated communities could have added value to the impact of culture on drinking water perceptions among the communities in the region. Involving more than one community could have gauged the impact of the perceived impact of culture on drinking water perceptions. Each Aboriginal community is unique. Cross-cultural issues such as institutional processes, public trust, impersonal and interpersonal information sources and inter-cultural norms about drinking water risk perception were therefore limited in the study. Risk perception may not simply be about the issues in one community, but they may be a proxy for other ideological and socio-cultural problems (Doria, 2010). The findings and outcome of the study cannot be generalised as representative of Aboriginal communities in the region.

Furthermore, the study did not explore the perceptions of the general community to compare with the community under study. Other studies in urban setups in Australia indicate that many communities have issues with water hardness, taste and odour and prefer rainwater to reticulated supplies (Chubaka et al., 2017; Hurlimann and Dolnicar, 2010; Rodrigo et al., 2010). Many urban residents, unlike the Walhallow community, treat the rainwater before drinking. Water quality may be no longer a largely technical problem in Aboriginal communities, but cultural and behavioural issues may need attention in order to “close the gap” in indigenous health. A qualitative diagnostic approach to drinking water management policy inclusive of social determinants of risk perception is necessary to enhance public health. In Canada, Dupont et al. (2010) found that even in the general population, where issues of safe water are mostly an irrelevant issue, the majority of consumers believed that bottled water was safer than reticulated water.

The number of swimming sites in the study was small, which may affect their representativeness of the study base. Only three out of the seven sites were used as drinking water sources which limits their representativeness of drinking water sources. The study was carried out during a drought period which did not fully reflect the effects of heavy rainfall events and peak user densities. The study did not link the enterococci detections to any drinking water treatment problems or drinking water quality incidences.

8.6 Conclusion

The research project demonstrated the usefulness of centrally stored, routinely collected drinking water quality surveillance data to access public health risk and to recommend public health actions. Participation by environmental health practitioners, health managers, water suppliers, and communities in the research programs enhanced evidence data translation and successful policy change implementation.

The study demonstrated that there are benefits from developing and implementing drinking water quality management plans by water utilities. Water quality verification testing has improved (100% sampling adequacy) and water quality has improved (low *E. coli* detection rate). The general conclusion of the study is that developing and implementing drinking water quality management plans, including verification monitoring, is an important instrument in improving water quality and minimising the incidence of waterborne disease outbreaks and consequently improves public health.

Drinking water outbreaks exemplify known breaches in municipal water treatment and distribution processes, and the failure of regulatory requirements to ensure water that is free of human pathogens (Reynolds et al., 2008). The water utilities commitment to drinking water safety and the implementation of drinking water management systems may have prevented outbreaks in Hunter New England region. The evaluation of the NSW drinking water monitoring program indicated potential waterborne disease outbreaks. However, there is need to guard against false alerts/alarms which may have substantial undue economic and social consequences in small rural communities. Evaluation is a form of surveillance which contributes to the protection of public health by promoting improvement of the quality and safety of water supplies (WHO, 2001). It is both preventive (detecting risks) and remedial (recommending prompt corrective action; policy changes) before disease outbreaks can occur. Water monitoring programs alone generally lack representativeness and have poor predictive value; results need to be interpreted with caution (Hrudey and Leiss, 2003).

Drinking water safety is more than catchment management and treatment is intricately linked with socio-cultural factors. Understanding the socio-cultural issues influencing drinking water perceptions is essential and requires interdisciplinary collaboration. Environmental health practitioners need to facilitate research for policy change by utilising general daily practice data and systematically connecting the research practice, evidence translation and intervention to existing practices. This research provided a platform for further cooperative environmental health work between practitioners, academics and policy makers for the benefit of public health.

While there has been much improvement in water quality throughout rural Hunter New England, a key challenge for many utilities is safeguarding water supplies for small communities and recreational parks and consumer confidence in discrete Aboriginal communities. A multi-barrier approach is the fundamental best practice paradigm for water safety, and monitoring is a key protective function for best practice verification and appropriate response to any adverse event (Huck and Coffey, 2004). Growing demands on environmental health create an urgent need to link research, practice and policy to improve public health especially drinking water quality.

Stakeholder involvement was necessary to ensure coordination and cooperation with key partners for financial and resources mobilisation to steer policy change. The research has resulted in benefits to utilities in rural NSW including a mechanism to regularly review their water quality, fostering better communication with Public Health Units, NSW Water and communities, upskilling of staff on water management, knowledge transfer between utilities and improved communication with regulators, with the common aim of providing safer water to the community. Collaboration with technical experts, external stakeholders helped knowledge transfer and upskilling of water supply operators and ensured a more diligent approach to the management of drinking water quality.

Practitioner leadership for policy change gives practice, governance, representation, responsibility, and accountability as well as advocacy for change implementation. Environmental health on the job training in the research field related to policy change was enhanced by the involvement of academics to mentor the research process as the external change agents (Alagoz et al., 2018). However, there may be differences between practitioners and academics about the way that problems are identified and addressed (Jansen et al., 2010). Differences regarding timing, resources, use of theory, and focus on internal versus external validity make partnerships problematic (Denford et al., 2018). Thus, stakeholder involvement in the research design and development of any partnership is essential.

The long-term challenges for public health authorities and utilities is the sustainable maintenance and vigilance in the provision of funding for rural water utilities to continuously implement systematic operational data collection and verification as an essential component of drinking water management.

The other challenges involve sustainable cooperation between environmental health practitioners, policy-makers, academics, stakeholders and consumers to work collaboratively on drinking water management and thus narrow the gap between policy and research and practice. Future developments need to focus on linking environmental health practitioner's fieldwork using established collaborative networks between academics and policy makers in the diverse environmental health network as an invaluable resource that provides evidence-based policy changes for public health benefit.

Afterword

“Water is one of the critical elements to life. If you take care of the water spirit, it will remain happy and will provide for your needs. The elders have told us that a time will come when there will be a scarcity of clean water. Once we were able to drink from any lake or stream. Those days are gone. The prophecy has come to pass”- Violet Poitras, Elder, Paul First Nation, Canada (Duncan and Bowden, 2009).

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Appendices

Appendix 1: Characteristics of Drinking Water Systems in Regional Hunter New England 2014

Water Utility	Supply System	First data entry date	Primary source	Treatment (Clarification)	Disinfection	Population served	Allocated samples/year	Total samples expected 2001-2015	Total samples collected 2001-2015	% sampling rate	*E.coli* detections 2001-2015	% *E. coli* detection rate
Armidale Dumaresq Council	Armidale	28/03/01	Dam	Clarification	Chlorination	24100	112	1507	1261	83.7	6	0.5
Glen Innes Severn Shire Council	Deepwater	18/01/01	River	No treatment	Chlorination	350	26	363	351	96.7	22	6.3
Glen Innes Severn Shire Council	Glen Innes	07/02/01	Dam	Clarification	Chlorination	6300	52	719	309	43.0	17	5.5
Gunnedah Shire Council	Curlewis	23/01/01	Bore	No treatment	Chlorination	610	52	721	614	85.2	24	3.9
Gunnedah Shire Council	Gunnedah	23/01/01	Bore	No treatment	Chlorination	9540	64	901	746	82.8	26	3.5
Gunnedah Shire Council	Mullaley	16/01/01	Bore	No treatment	Chlorination	80	12	180	142	78.9	9	6.3
Gunnedah Shire Council	Tambar Springs	16/01/01	Bore	No treatment	Chlorination	99	12	180	149	82.8	15	10.1

Guyra Shire Council	Guyra	31/01/01	River	Clarification	Chlorination	200	52	743	724	97.4	16	2.1
Guyra Shire Council	Tingha	14/01/01	Dam	Clarification	Chlorination	732	12	254	242	95.3	0	0.0
Gwydir Shire Council	Bingara	08/03/01	River	Clarification	Chlorination	1300	52	719	701	97.5	27	3.9
Gwydir Shire Council	Gravesend	15/03/01	Bore	No treatment	Chlorination	180	26	359	343	95.5	44	12.8
Gwydir Shire Council	North Star	28/06/01	Bore	No treatment	Chlorination	80	12	180	150	83.3	7	4.7
Gwydir Shire Council	Warialda	08/03/01	Bore	No treatment	Chlorination	1300	52	721	699	96.9	8	1.1
Inverell Shire Council	Ashford	21/02/01	River	Clarification	Chlorination	400	26	440	352	51.0	1	0.3
Inverell Shire Council	Copeton	20/01/01	Dam	Clarification	Chlorination	12000	88	1277	709	55.5	4	0.6
Inverell Shire Council	Yetman	20/01/01	Bore	No treatment	Chlorination	80	26	358	214	59.8	1	0.5
Liverpool Plains Shire Council	Blackville	19/09/01	Bore	No treatment	Chlorination	30	26	240	191	79.6	5	2.6

Liverpool Plains Shire Council	Caroona	19/09/01	Bore	No treatment	Chlorination	30	26	378	236	62.4	9	3.8
Liverpool Plains Shire Council	Premer	19/09/01	Bore	No treatment	Chlorination	115	26	279	215	77.1	3	1.4
Liverpool Plains Shire Council	Quirindi	19/09/01	Bore	No treatment	Chlorination	3000	52	719	470	65.4	7	1.5
Liverpool Plains Shire Council	Spring Ridge	19/09/01	Bore	No treatment	Chlorination	120	26	359	235	65.5	0	0.0
Liverpool Plains Shire Council	Walhallow	30/01/01	Bore	No treatment	Chlorination	178	26	377	248	65.8	7	2.8
Liverpool Plains Shire Council	Wallabadah	19/09/01	Bore	No treatment	Chlorination	200	26	360	233	64.4	2	0.9
Liverpool Plains Shire Council	Werris Creek	30/01/01	Dam	Clarification	Chlorination	1600	26	719	576	80.1	18	3.1
Liverpool Plains Shire Council	Willow Tree	13/02/01	Bore	No treatment	Chlorination	230	26	360	318	88.3	0	0.0

Midcoast Water	Bulahdelah	13/02/01	River	Clarification	Chlorination	1500	52	721	709	98.3	3	0.4
MidCoast Water	Gloucester	16/01/01	River	Clarification	Chlorination	3100	78	847	1357	100.0	66	4.9
MidCoast Water	Karuah River (Stroud)	27/02/01	River	Clarification	Chlorination	1000	52	721	708	98.2	0	0.0
MidCoast Water	Manning District WSS	05/02/01	River	Clarification	Chlorination	52904	479	6595	5889	89.3	49	0.8
MidCoast Water	North Karuah	05/02/01	Bore	Clarification	Chlorination	100	26	360	353	98.1	6	1.7
MidCoast Water	Viney Creek /Tea Gardens	05/02/01	Bore	pH correction	Chlorination	3824	52	721	707	98.1	15	2.1
Moree Plains Shire Council	Boggabilla	22/01/01	River	Clarification	Chlorination	639	26	359	368	100.0	5	1.4
Moree Plains Shire Council	Moree	12/02/01	Bore	pH correction	Chlorination	10350	88	931	965	100.0	2	0.2
Moree Plains Shire Council	Mungindi	19/02/01	River	Clarification	Chlorination	648	26	626	617	98.6	21	3.4
Moree Plains Shire Council	Pallamallawa	24/05/01	Bore	Aeration	Chlorination	309	26	310	318	100.0	4	1.3
Moree Plains Shire Council	Toomelah	22/01/01	Bore	No treatment	Chlorination	125	26	372	306	82.3	17	5.6

Muswellbrook Shire Council	Denman	10/04/01	Mixed	Clarification	Chlorination	2000	52	719	736	100.0	5	0.7
Muswellbrook Shire Council	Muswellbrook	28/03/01	River	Clarification	Chlorination	11000	64	899	903	100.0	0	0.0
Muswellbrook Shire Council	Sandy Hollow	28/03/01	Bore	Clarification	Chlorination	264	26	359	371	100.0	3	0.8
Narrabri Shire Council	Bellata	29/01/01	Bore	No treatment	Chlorination	186	26	360	343	95.3	11	3.2
Narrabri Shire Council	Boggabri	23/01/01	Bore	No treatment	Chlorination	950	52	720	689	95.7	4	0.6
Narrabri Shire Council	Gwabegar	23/01/01	Bore	No treatment	Chlorination	125	26	360	357	99.2	1	0.3
Narrabri Shire Council	Narrabri	23/01/01	Bore	No treatment	Chlorination	7200	52	720	694	96.4	6	0.9
Narrabri Shire Council	Pilliga	23/01/01	Bore	No treatment	Chlorination	150	26	360	346	96.1	0	0.0
Narrabri Shire Council	Wee Waa	23/01/01	Bore	No treatment	Chlorination	1800	52	720	688	95.6	3	0.4
Seal Rocks Holiday Park	Seal Rocks	22/10/01	Bore	No treatment	Silver Ion	200	12	212	146	53.1	2	1.4
Singleton Shire Council	Jerrys Plains	13/04/04	River	Clarification	Chlorination	200	26	288	298	100.0	0	0.0

Singleton Shire Council	Singleton	02/05/01	Dam	Clarification	Chlorination	19927	150	1361	1299	95.4	3	0.2
Tamworth Regional Council	Attunga	30/01/01	Bore	No treatment	Chlorination	400	26	358	367	100.0	1	0.3
Tamworth Regional Council	Barraba	07/02/01	Mixed	Clarification	Chlorination	1400	52	718	712	99.2	4	0.6
Tamworth Regional Council	Bendemeer	30/01/01	River	Clarification	Chlorination	265	26	360	368	100.0	26	7.1
Tamworth Regional Council	Manilla	03/07/01	River	Clarification	Chlorination	2300	52	721	715	99.2	1	0.1
Tamworth Regional Council	Moonbi/Kootingal	06/02/01	Bore	No treatment	Chlorination	3400	52	720	650	90.3	11	1.7
Tamworth Regional Council	Nundle	25/09/01	Mixed	Clarification	Chlorination	250	26	368	365	99.2	5	1.4
Tamworth Regional Council	Tamworth	17/01/01	Dam	Clarification	Chlorination	45000	148	2156	2014	93.4	18	0.9
Tenterfield Shire Council	Tenterfield	08/01/04	River	Clarification	Chlorination	3300	52	694	454	65.4	1	0.2

Tenterfield Shire Council	Wallangarra	08/01/04	River	Clarification	Chlorination	250	26	386	277	71.8	2	0.7
Upper Hunter Shire Council	Aberdeen	13/03/01	Mixed	No treatment	Chlorination	2000	52	717	743	100.0	8	1.1
Upper Hunter Shire Council	Cassilis	30/01/01	Bore	No treatment	Chlorination	100	26	360	348	96.7	0	0.0
Upper Hunter Shire Council	Merriwa	30/01/01	Bore	Clarification	Chlorination	1000	52	719	732	100.0	3	0.4
Upper Hunter Shire Council	Murrurundi	13/02/01	River	Clarification	Chlorination	902	52	719	647	90.0	4	0.6
Upper Hunter Shire Council	Scone	27/02/01	Mixed	No treatment	Chlorination	3468	78	1181	1049	88.8	1	0.1
Uralla Shire Council	Bundarra	06/02/01	River	Clarification	Chlorination	400	26	360	347	96.4	9	2.6
Uralla Shire Council	Uralla	06/02/01	Dam	Clarification	Chlorination	2500	52	720	632	87.8	12	1.9
Walcha Council	Summervale	12/04/01	Bore	No treatment	Ultraviolet	30	12	193	135	69.9	2	1.5
Walcha Council	Walcha	10/04/01	Dam	Clarification	Chlorination	1730	52	720	594	82.5	1	0.2
Sum total						250050	3293	45224	40744	90.1	618	1.5

Appendix 2: Annual Sampling Adequacy by Water Supply System Hunter New England, 2001-2015

System	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Armidale	18.8	70.8	90.6	96.9	92.7	91.7	89.6	83.3	92.7	91.7	88.5	88.9	86.1	83.48	80
Deepwater	100	100	83.3	91.7	100	100	95.8	100	100	100	91.7	83.3	87.5	100	100
Glen Innes	33.3	33.3	25	25	25	22.9	18.8	27.1	16.7	25	25	58.3	100	100	100
Curlewis	83.3	100	66.7	58.3	50	75	75	91.7	97.9	95.8	72.9	91.7	100	100	100
Gunnedah	73.3	86.7	51.7	71.7	46.7	73.3	75	90	91.7	96.7	88.3	81.7	100	100	100
Mullaley	75	66.7	58.3	75	41.7	66.7	66.7	91.7	91.7	83.3	83.3	91.7	91.7	100	100
Tambar Springs	75	83.3	58.3	75	50	75	83.3	91.7	100	83.3	91.7	91.7	91.7	100	100
Guyra	56.7	85	77.1	87.5	100	100	93.8	100	100	100	97.9	100	100	100	100
Tingha	91.7	41.7	100	66.7	100	91.7	75	100	100	91.7	91.7	100	100	100	100
Bingara	37.5	91.7	93.8	100	100	100	100	100	100	100	100	100	100	100	100
Gravesend	20.8	50	91.7	100	91.7	100	100	100	100	100	100	100	100	100	100
North Star	16.7	58.3	41.7	100	100	91.7	83.3	91.7	91.7	91.7	91.7	91.7	100	100	100
Warialda	47.9	87.5	72.9	95.8	100	100	100	100	100	100	100	100	100	100	100
Ashford	14.6	100	94	100	100	100	100	100	87	59	67	100	100	100	100

Copeton	10.4	52.1	32.5	32.1	34.5	33.3	35.7	33.3	28.6	71.4	72.6	98.8	100	100	100
Yetman	41.7	79.2	100	79	100	100	100	100	100	67	67	100	100	100	100
Blackville	8.3	0	0	0	83.3	25	83.3	91.7	100	100	95.8	100	100	100	100
Caroona	4.2	0	0	0	33.3	6.7	100	100	100	100	100	100	100	100	100
Premer	8.3	0	0	0	83.3	16.7	100	50	100	100	100	100	100	100	100
Quirindi	2.1	0	0	0	66.7	18.8	89.6	100	100	93.8	95.8	100	100	97.92	100
Spring Ridge	4.2	0	0	0	41.7	8.3	100	100	95.8	100	100	100	100	100	100
Walhallow	41.7	33.3	0	0	0	41.7	100	100	100	66.7	85.2	95.8	96	100	100
Wallabadah	4.2	0	0	0	45.8	12.5	95.8	100	100	100	91.7	91.7	100	100	100
Werris Creek	66.7	91.7	66.7	43.8	0	35.4	89.6	100	100	100	93.8	100	100	97.92	100
Willow Tree	87.5	95.8	91.7	83.3	0	41.7	100	100	100	100	95.8	100	100	100	100
Bulahdelah	97.9	100	100	100	56.3	54.2	100	100	100	100	100	100	100	100	100
Gloucester	100	100	100	100	100	100	100	100	100	100	100	84.8	89.9	98.73	98.7
Karuah River	93.8	100	100	100	50	54.2	100	100	100	100	100	100	100	100	100
Manning District	92.5	97.1	97.6	95.9	48.7	23.3	99.3	94.1	95.8	97.4	98.9	95	94.6	99.78	99.3
North Karuah	95.8	100	100	100	50	58.3	100	100	100	100	100	100	100	100	100

Tea gardens	93.8	100	100	100	50	54.2	100	100	100	100	100	100	100	100	100
Boggabilla	100	100	100	100	70.8	87.5	100	91.7	100	100	100	91.7	100	100	100
Moree	0	100	100	100	75	90	91.7	100	100	100	100	89.3	100	100	100
Mungindi	0	100	91.7	100	81.3	89.6	89.6	95.8	91.7	100	100	91.7	100	100	100
Pallamallawa	0	100	100	100	87.5	83.3	91.7	95.8	91.7	100	91.7	83.3	100	100	100
Toomelah	95.8	50	100	100	37.5	45.8	37.5	79.2	87.5	69.4	96	92	100	100	100
Denman	70.8	95.8	100	100	100	100	100	100	100	100	100	100	93.8	100	100
Muswellbrook	68.3	90	98.3	100	100	100	100	100	100	100	100	100	95	100	100
Sandy Hollow	66.7	100	95.8	100	100	100	100	100	100	100	100	100	95.8	100	100
Bellata	37.5	95.8	87.5	100	100	100	100	100	87.5	95.8	100	95.8	100	100	100
Boggabri	35.4	95.8	83.3	97.9	100	100	100	100	89.6	97.9	100	100	100	100	100
Gwabegar	41.7	100	87.5	100	100	100	100	100	83.3	95.8	100	100	100	100	100
Narrabri	39.6	93.8	87.5	100	100	97.9	100	100	87.5	100	100	100	100	100	100
Pilliga	41.7	100	87.5	100	100	95.8	95.8	100	87.5	95.8	100	100	100	100	100
Wee Waa	37.5	97.9	87.5	95.8	100	97.9	100	100	87.5	97.9	100	100	100	100	100
Seal Rocks	0	37.5	100	33.3	33.3	45.8	41.7	41.7	76.9	100	100	25	50	0	0

Jerrys Plains	0	0	0	100	87.5	100	100	100	100	100	100	100	100	91.67	100
Singleton	100	73.3	96.7	100	100	40	100	15	100	61.7	98	100	96	94.7	96
Attunga	100	91.7	91.7	79.2	100	100	100	100	100	100	100	100	100	100	100
Barraba	35.4	100	100	85.4	100	100	95.8	100	100	100	100	100	100	100	100
Bendemeer	95.8	95.8	95.8	75	100	100	100	100	100	100	100	100	100	100	100
Manilla	43.8	89.6	100	100	100	100	100	100	100	100	100	100	100	100	100
Moonbi/Kootingal	95.8	97.9	64.6	45.8	50	54.2	100	100	100	100	100	100	100	100	100
Nundle	17.9	95.8	100	100	100	100	100	100	100	52.1	95.8	100	100	100	100
Tamworth	75.6	94.5	94.5	95.3	94.5	91.3	92.1	95.4	99.3	94.7	96.7	92.7	94	98.85	98.9
Wallangarra	0	0	0	91.7	100	100	100	50	100	100	100	70.8	50	8.33	25
Tenterfield	0	0	0	75	68.8	87.5	75	54.6	100	100	100	85.4	91.7	83.33	100
Aberdeen	72.9	97.9	100	100	100	91.7	100	85.4	100	100	100	100	100	100	100
Cassilis	95.8	100	100	100	87.5	100	91.7	83.3	100	100	95.8	100	87.5	100	91.7
Merriwa	81.3	100	100	100	100	97.9	100	81.3	100	97.9	95.8	97.9	95.8	100	100
Murrurundi	100	91.7	75	81.3	39.6	83.3	77.1	85.4	85.4	100	97.9	97.9	100	100	100
Scone	50.6	98.7	100	86.3	100	83.5	81	74.7	86.1	91.1	91.1	96.2	88.6	96.2	93.7

Bundarra	91.7	100	95.8	83.3	95.8	100	100	100	95.8	91.7	75	87.5	95.8	95.83	83.3
Uralla	45.8	50	47.9	43.8	45.8	100	100	100	100	100	100	100	100	100	100
Summervale	58.3	0	83.3	42.1	63.2	100	91.7	100	100	100	100	91.7	100	0	0
Walcha	37.5	45.8	50	66.7	75	75	75	87.5	93.8	100	100	100	100	100	100
Systems Combined	64.2	85	82.1	85.1	75	72.9	93.7	91.5	96.6	96.3	97.3	95.8	97.8	98.5	100
Mean	58.2	85.4	85.6	85.7	74.8	75.9	90.6	90.2	94.3	93.3	94.2	94.5	96.5	97.6	97.9

Legend
Orange = <90 % non-compliant
Yellow = 90 - <98% compliant
Green = 98 - 100 % fully compliant
No fill = Not part of the program

Appendix 3: Monthly Sampling Adequacy by System Regional Hunter New England, 2001-2015

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Armidale	76.4	78.2	87.4	69.4	90.6	82.3	99.2	98.4	92.8	75.6	89.5	56.7
Deepwater	100	93.3	100	100	96.7	100	100	100	80	100	90	90
Glen Innes	40	45	48.3	41.7	48.3	43.3	45	43.3	43.3	46.7	40	30
Curlewis	90	80	96.7	78.3	85	71.7	76.7	88.3	100	88.3	98.3	70
Gunnedah	89.3	78.7	89.3	76	82.7	68	74.7	85.3	100	89.3	85.3	70.7
Mullaley	86.7	73.3	93.3	73.3	80	73.3	80	66.7	100	86.7	80	53.3
Tambar Springs	93.3	86.7	93.3	73.3	86.7	73.3	80	73.3	100	93.3	86.7	60
Guyra	83.9	88.7	100	71	100	100	100	100	95.2	100	90.3	67.7
Tingha	66.7	81	85.7	52.4	100	85.7	81	100	100	100	95.2	100
Bingara	76.7	81.7	96.7	75	100	96.7	98.3	100	100	90	100	100
Gravesend	66.7	90	90	100	83.3	66.7	96.7	86.7	100	100	100	100
North Star	40	86.7	53.3	60	80	73.3	100	53.3	86.7	60	100	100
Warialda	73.3	81.7	100	83.3	100	96.7	96.7	100	100	96.7	100	90
Ashford	80	93.8	100	81.3	100	100	100	96.9	75.8	93.8	75	64.7

Copeton	50	51.4	64.5	52.3	56.1	58.9	57	84.1	53.3	56.1	44.9	36.4
Yetman	57.1	56.7	76.7	66.7	63.3	63.3	63.3	66.7	46.7	60	50	43.3
Blackville	75	75	95	80	80	75	75	75	100	84.2	80	60
Caroona	60	53.3	76.7	66.7	66.7	73.3	66.7	66.7	80	41.7	63.3	46.7
Premer	69.6	69.6	80	78.3	73.9	91.3	73.9	78.3	95.7	82.6	69.6	65.2
Quirindi	61.7	63.3	71.7	68.3	65	71.7	70	65	73.3	63.3	61.7	48.3
Spring Ridge	62.1	56.7	73.3	66.7	66.7	73.3	96.7	63.3	73.3	53.3	56.7	43.3
Walhallow	65.6	67.7	64.7	75	67.7	71	67.7	61.3	71	74.2	54.8	48.4
Wallabadah	63.3	56.7	73.3	66.7	63.3	60	66.7	66.7	83.3	70	63.3	43.3
Werris Creek	73.3	71.7	83.3	91.7	76.7	81.7	83.3	81.7	98.3	80	76.7	61.7
Willow Tree	70	90	100	93.3	100	100	83.3	96.7	90	90	73.3	56.7
Bulahdelah	100	100	100	100	100	100	100	88.3	96.7	91.7	96.7	90
Gloucester	100	100	100	100	100	100	100	100	100	100	100	100
Karuah River	98.3	98.3	100	100	100	100	100	90	100	91.7	90	90
Manning District	93.9	98.6	100	94.1	88.4	94.4	87	84.7	90.4	82.5	86.1	69.5
North Karuah	100	100	100	100	100	100	93.3	86.7	100	93.3	90	90

Tea gardens	100	100	100	100	100	100	98.3	90	96.7	91.7	90	91.7
Boggabilla	93.3	76.7	100	100	100	100	100	100	100	93.3	100	83.3
Moree	79.2	77.9	100	100	100	100	100	100	100	100	94.8	70.1
Mungindi	78.8	94.2	100	100	100	100	100	90.4	100	100	100	57.7
Pallamallawa	96.2	88.5	100	100	100	92.3	100	100	76.9	100	88.5	69.2
Toomelah	58.1	71	96.8	83.9	71	80.6	90.3	84.8	83.9	77.4	100	74.2
Denman	98.3	86.2	100	100	100	100	100	100	100	100	100	100
Muswellbrook	100	81.3	100	94.7	100	98.7	100	100	100	100	100	100
Sandy Hollow	100	86.7	100	100	100	100	100	100	100	100	100	60
Bellata	93.3	93.3	100	96.7	100	100	96.7	96.7	100	100	96.7	60
Boggabri	98.3	91.7	100	98.3	95	96.7	100	98.3	96.7	95	96.7	73.3
Gwabegar	96.7	96.7	100	100	96.7	96.7	100	100	93.3	96.7	100	76.7
Narrabri	98.3	95	100	100	93.3	96.7	100	98.3	96.7	100	91.7	78.3
Pilliga	93.3	100	100	96.7	96.7	86.7	100	96.7	93.3	100	96.7	70
Wee Waa	96.7	91.7	100	100	100	96.7	100	98.3	96.7	98.3	93.3	70
Seal Rocks	0	21.7	100	56.5	30.4	56.5	43.5	39.1	47.8	52.2	65.2	91.3

Jerrys Plains	91.7	91.7	100	100	100	100	100	100	100	100	100	79.2
Singleton	100	100	100	100	87.8	98.2	95.7	100	100	95.7	74.5	51.3
Attunga	100	100	90	100	96.7	96.7	100	96.7	100	96.7	100	100
Barraba	86.7	85	100	98.3	96.7	100	90	100	100	93.3	100	88.3
Bendemeer	100	86.7	83.3	100	100	100	96.7	93.3	100	96.7	100	93.3
Manilla	100	86.7	96.7	95	100	100	100	100	100	100	100	88.3
Moonbi/Kootingal	86.7	75	80	95	85	83.3	85	81.7	100	100	100	93.3
Nundle	91.2	86.7	92.1	83.3	100	100	100	100	100	100	93.3	100
Tamworth	88.1	83.5	86.5	95.9	87.5	94.7	98.4	97.8	100	90.8	100	100
Wallangarra	67.6	94.1	100	68.8	62.5	75	65.6	68.8	81.3	62.5	68.8	40.6
Tenterfield	74.1	68.5	65.5	58.6	60.3	55.2	60.3	46.6	74.1	79.3	63.8	86.2
Aberdeen	70	100	100	100	100	100	100	100	100	93.3	83.3	46.7
Cassilis	73.3	100	100	86.7	100	100	100	100	93.3	100	96.7	83.3
Merriwa	80	85	100	90	100	100	100	100	100	100	100	75
Murrurundi	56.7	100	91.7	93.3	98.3	96.7	100	100	88.3	100	75	65
Scone	53.3	91.1	84.8	91.1	86.7	98.9	88.6	100	100	94.3	100	54.3

Bundarra	83.3	100	100	93.3	100	100	100	96.7	100	100	90	76.7
Uralla	85	91.7	95	86.7	95	93.3	91.7	85	90	85	90	65
Summervale	66.7	73.3	80	73.3	73.3	37.9	73.3	73.3	86.7	73.3	80	73.3
Walcha	73.3	78.3	78.3	81.7	83.3	83.3	88.3	86.7	86.7	83.3	85	81.7

Legend

Orange = <90% non-compliant

Yellow = 90 - <98% compliant

Green = 98 - 100 % fully compliant

No fill = Not part of program

Appendix 4: Annual E. coli Detections by Water Supply System, Regional Hunter New England, 2001-2015

System	Source Group	Population Group	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	Total detections	Total samples collected 2001-2015	% *E. coli* detection rate
Armidale	1	4	0	1	1	1	0	0	0	0	0	1	0	0	2	0	0	6	1261	0.5
Deepwater	2	2	3	5	5	3	0	2	3	0	0	0	1	0	0	0	0	22	351	6.3
Glenn Innes	1	4	2	0	0	6	2	3	1	2	0	0	0	1	0	0	0	17	309	5.5
Curlewis	3	3	5	6	3	4	2	0	0	0	1	2	1	0	0	0	0	24	614	3.9
Gunnedah	3	4	3	3	4	3	4	3	3	3	0	0	0	0	0	0	0	26	746	3.5
Mullaley	3	1	0	1	1	2	1	1	0	0	0	0	0	1	1	0	1	9	142	6.3
Tambar Springs	3	1	1	1	0	5	2	1	2	1	0	1	0	0	1	0	0	15	149	10.1
Guyra	2	2	1	0	2	7	5	1	0	0	0	0	0	0	0	0	0	16	724	2.1
Tingha	1	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	242	0.0
Bingara	2	3	3	7	0	6	3	0	2	2	3	0	1	0	0	0	0	27	701	3.9
Gravesend	3	2	3	10	6	11	9	1	0	0	1	0	1	0	2	0	0	44	343	12.8
North Star	3	1	1	4	0	0	0	0	0	0	0	0	0	0	2	0	0	7	150	4.7
Warialda	3	3	1	1	0	3	2	0	0	0	0	0	0	0	0	1	0	8	699	1.1

Ashford	2	2	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	352	0.3
Copeton	1	4	0	0	0	0	0	0	0	0	0	1	0	0	1	2	0	4	709	0.6
Yetman	3	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	214	0.5
Blackville	3	1	0	0	0	0	1	1	1	0	0	0	1	1	0	0	0	5	191	2.6
Caroona	3	1	1	3	0	0	4	0	0	0	1	0	0	0	0	0	0	9	236	3.8
Premer	3	2	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	3	215	1.4
Quirindi	3	3	0	0	0	0	4	3	0	0	0	0	0	0	0	0	0	7	470	1.5
Spring Ridge	3	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	235	0.0
Walhallow	3	2	4	2	0	0	0	1	0	0	0	0	0	0	0	0	0	7	248	2.8
Wallabadah	3	2	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	2	233	0.9
Werris Creek	1	3	12	4	1	0	0	0	0	0	1	0	0	0	0	0	0	18	576	3.1
Willow Tree	3	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	318	0.0
Bulahdelah	2	3	0	0	0	0	0	1	2	0	0	0	0	0	0	0	0	3	709	0.4
Gloucester	2	3	12	5	10	3	5	2	2	6	6	7	7	0	1	0	0	66	1357	4.9
Stroud	2	3	1	0	1	0	0	1	0	0	0	0	0	1	0	1	0	5	708	0.0
Manning District	2	4	5	5	7	10	2	3	6	2	3	2	0	2	1	1	0	49	5889	0.8
North Karuah	3	2	2	0	0	1	0	0	0	0	0	0	1	1	0	1	0	6	353	1.7

Tea Gardens	3	3	3	5	4	0	0	0	2	0	1	0	0	0	0	0	0	15	707	2.1
Boggabilla	2	3	0	0	2	0	0	0	1	0	1	1	0	0	0	0	0	5	368	1.4
Moree	3	4	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	2	965	0.2
Mungindi	2	3	1	0	1	1	3	2	4	1	3	2	0	0	2	1	0	21	617	3.4
Pallamallawa	3	2	2	0	1	1	0	0	0	0	0	0	0	0	0	0	0	4	318	1.3
Toomelah	3	2	0	0	0	2	1	4	2	6	1	0	0	0	0	1	0	17	306	5.6
Denman	4	3	0	0	1	1	2	0	0	0	0	0	0	1	0	0	0	5	736	0.7
Muswellbrook	2	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	903	0.0
Sandy Hollow	3	2	2	0	0	0	1	0	0	0	0	0	0	0	0	0	0	3	371	0.8
Bellata	3	2	1	3	0	1	0	3	1	1	0	1	0	0	0	0	0	11	343	3.2
Boggabri	3	3	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	689	0.6
Gwabegar	3	2	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	357	0.3
Narrabri	3	4	0	0	2	1	1	0	0	0	0	0	1	0	0	1	0	6	694	0.9
Pilliga	3	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	346	0.0
Wee Waa	3	3	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	3	688	0.4
Seal Rocks	3	2	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	2	146	1.4
Jerry's Plains	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	298	0.0

Singleton	1	4	0	0	1	0	1	0	0	0	0	0	1	0	0	0	0	3	1299	0.2
Attunga	3	2	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	367	0.3
Barraba	4	3	0	2	1	0	0	0	0	0	0	0	0	0	1	0	0	4	712	0.6
Bendemeer	2	2	5	9	2	2	4	2	0	1	0	0	0	1	0	0	0	26	368	7.1
Manilla	2	3	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	715	0.1
Moonbi/Kootingal	3	3	3	3	1	0	2	0	0	0	1	1	0	0	0	0	0	11	650	1.7
Nundle	4	2	0	1	0	0	1	0	0	0	1	2	0	0	0	0	0	5	365	1.4
Tamworth	1	4	2	5	1	5	1	0	0	0	0	0	0	1	0	3	0	18	2014	0.9
Tenterfield	2	3	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	454	0.2
Wallangarra	2	2	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	2	277	0.7
Aberdeen	4	3	0	0	0	0	0	0	7	0	1	0	0	0	0	0	0	8	743	1.1
Cassilis	3	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	348	0.0
Merriwa	3	3	2	0	0	0	0	0	1	0	0	0	0	0	0	0	0	3	732	0.4
Murrurundi	2	3	0	0	0	2	1	0	1	0	0	0	0	0	0	0	0	4	647	0.6
Scone	4	3	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1049	0.1
Bundarra	2	2	3	1	0	1	1	2	0	0	0	1	0	0	0	0	0	9	347	2.6
Uralla	1	3	3	1	0	3	1	1	0	1	2	0	0	0	0	0	0	12	632	1.9

Summervale	3	1	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	2	135	1.5
Walcha	1	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	594	0.2
Total			90	93	59	91	68	40	43	28	28	22	16	10	15	13	2	618	40744	1.5

Legend:
Source Group 1 = Dam
Source Group 2 = River
Source Group 3 = Bore
Source Group 4 = Mixed
Pop Group 1 = >100
Pop Group 2 = 100 - 499
Pop Group 3 = 500-4999
Pop Group 4 = >5000

Appendix 5. Monthly E. coli Detections by Drinking Water System, Regional Hunter New England, 2001-2015

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total	Collected samples	Detection rate
Armidale	2	1	0	0	0	0	0	0	0	0	2	1	6	1261	0.5
Deepwater	2	0	2	3	5	3	3	1	1	2	0	0	22	351	6.3
Glen Innes	0	1	4	2	2	1	1	0	0	2	3	1	17	309	5.5
Curlewis	5	1	2	4	3	1	2	0	2	2	1	1	24	614	3.9
Gunnedah	5	4	4	2	1	0	0	0	0	3	5	2	26	746	3.5
Mullaley	2	1	1	0	0	0	1	0	1	1	1	1	9	142	6.3
Tambar Springs	3	1	5	1	0	0	0	0	0	3	0	2	15	149	10.1
Guyra	3	2	2	2	0	1	1	1	1	1	0	1	15	724	2.1
Tingha	0	0	0	0	0	0	0	0	0	0	0	0	0	242	0.0
Bingara	3	5	5	1	5	0	1	0	4	1	0	2	27	701	3.9
Gravesend	5	6	4	6	4	1	2	3	7	2	2	2	44	343	12.8
North Star	0	0	0	1	1	1	1	0	0	1	0	2	7	150	4.7
Warialda	1	2	1	1	0	1	0	0	0	0	1	1	8	699	1.1
Ashford	0	1	0	0	0	0	0	0	0	0	0	0	1	352	0.3
Copeton	1	1	0	0	0	0	0	1	0	0	0	1	4	709	0.6
Yetman	0	1	0	0	0	0	0	0	0	0	0	0	1	214	0.5

Blackville	1	2	1	0	0	0	0	0	0	0	0	1	5	191	2.6
Caroona	1	1	2	1	0	1	0	0	1	0	0	2	9	236	3.8
Premer	0	0	0	1	0	1	0	0	0	1	0	0	3	215	1.4
Quirindi	1	1	2	0	1	0	0	0	0	0	1	1	7	470	1.5
Spring Ridge	1	0	0	0	0	0	0	0	0	0	0	0	1	235	0.0
Walhallow	2	2	1	1	0	0	0	0	0	1	0	0	7	248	2.8
Wallabadah	0	0	1	0	0	1	0	0	0	0	0	0	2	233	0.9
Werris Creek	2	2	0	3	1	1	0	0	1	0	5	3	18	576	3.1
Willow Tree	0	0	0	0	0	0	0	0	0	0	0	0	0	318	0.0
Bulahdelah	0	0	0	0	1	1	0	0	0	0	1	0	3	709	0.4
Gloucester	5	9	8	4	9	5	1	2	3	6	10	4	66	1357	4.9
Stroud	1	2	0	0	0	0	0	0	0	0	1	1	5	708	0.0
Manning District	10	6	2	7	1	2	0	0	4	4	9	4	49	5889	0.8
North Karuah	1	2	0	0	0	0	0	0	0	0	2	1	6	353	1.7
Tea gardens	2	0	2	0	0	0	1	1	1	2	4	2	15	707	2.1
Boggabilla	1	1	0	1	0	0	0	0	0	0	2	0	5	368	1.4
Moree	0	0	0	0	1	0	0	0	0	0	1	0	2	965	0.2
Mungindi	4	2	1	1	2	0	2	0	2	2	4	1	21	617	3.4

Pallamallawa	0	1	0	0	0	0	1	0	0	1	1	0	4	318	1.3
Toomelah	0	1	4	3	2	0	1	1	0	0	2	3	17	306	5.6
Denman	0	1	1	1	0	0	0	1	0	1	0	0	5	736	0.7
Muswellbrook	0	0	0	0	0	0	0	0	0	0	0	0	0	903	0.0
Sandy Hollow	0	0	1	0	0	1	0	0	0	1	0	0	3	371	0.8
Bellata	1	0	0	1	0	0	0	1	2	3	3	0	11	343	3.2
Boggabri	1	3	0	0	0	0	0	0	0	0	0	0	4	689	0.6
Gwabegar	0	0	0	0	0	0	0	0	0	0	0	1	1	357	0.3
Narrabri	2	1	0	0	0	1	0	0	0	0	2	0	6	694	0.9
Pilliga	0	0	0	0	0	0	0	0	0	0	0	0	0	346	0.0
Wee Waa	0	0	0	0	0	2	1	0	0	0	0	0	3	688	0.4
Seal Rocks	0	0	0	0	0	0	0	0	0	0	1	1	2	146	1.4
Jerrys Plains	0	0	0	0	0	0	0	0	0	0	0	0	0	298	0.0
Singleton	0	2	0	0	0	0	0	1	0	0	0	0	3	1299	0.2
Attunga	0	1	0	0	0	0	0	0	0	0	0	0	1	367	0.3
Barraba	1	0	1	0	0	0	0	0	0	0	1	1	4	712	0.6
Bendemeer	5	3	1	3	2	3	1	2	1	2	3	0	26	368	7.1
Manilla	0	0	0	0	0	0	0	1	0	0	0	0	1	715	0.1

Moonbi/Kootingal	3	2	1	0	0	0	0	0	0	0	2	3	11	650	1.7
Nundle	1	0	1	0	0	0	1	0	0	0	1	1	5	365	1.4
Tamworth	5	2	1	1	1	1	0	1	1	0	2	3	18	2014	0.9
Wallangarra	1	0	0	0	0	1	0	0	0	0	0	0	2	454	0.2
Tenterfield	0	0	0	0	0	0	0	0	0	0	1	0	1	277	0.7
Aberdeen	0	0	3	2	1	0	1	0	0	1	0	0	8	743	1.1
Cassilis	0	0	0	0	0	0	0	0	0	0	0	0	0	348	0.0
Merriwa	0	0	0	0	2	0	0	0	1	0	0	0	3	732	0.4
Murrurundi	0	1	0	0	1	0	0	0	0	0	1	1	4	647	0.6
Scone	0	0	0	0	0	0	0	0	1	0	0	0	1	1049	0.1
Bundarra	2	0	1	1	1	0	0	0	0	0	1	3	9	347	2.6
Uralla	1	2	1	0	1	0	1	0	1	1	2	2	12	632	1.9
Summervale	0	1	0	0	0	1	0	0	0	0	0	0	2	135	1.5
Walcha	0	1	0	0	0	0	0	0	0	0	0	0	1	594	0.2
Total	87	79	66	54	48	31	23	17	35	44	78	56	618	40744	1.5
Seasonal	222			168			71			157			618		

Appendix 6: Recreational Parks Survey Checklist

HUNTER NEW ENGLAND
NSW HEALTH

Survey and Assessment of

Water supplies in National and NSW State Parks

Park: Local Government Area: Date:

Water Source: ☐ Rainwater ☐ River/Creek ☐ Other____________

Intended Use: ☐ Toilet flushing ☐ Drinking ☐ Other______________

Main use of Park: ☐ Recreation ☐Camping ☐ Other ____________

Main human activity in the neighbourhood: ____________________________

Tanks:

Number of water tanks:	
Tank material:	☐ Galvanised steel ☐ Plastic ☐ Concrete ☐ Other _______________________
Type of the tank:	☐ Above ground ☐ Below ground ☐ Other________________________

Age of the tank/s:		
Capacity of the tank/s:		
Approximate Water Level in the tank/s:		☐ Empty ☐ ¼ full ☐ > ½ full ☐ full
Is the roof painted?		Yes ☐ No ☐
if yes …	Painted roof intact?	Yes ☐ No ☐
Does the tank have any access hatch?		Yes ☐ No ☐
Does the tank have an impervious cover to prevent entry of dust, debris & insects?		Yes ☐ No ☐
Does the inlet incorporate an insect-proof mesh/screen/strainer?		Yes ☐ No ☐
Does the overflow incorporate an insect-proof mesh/screen?		Yes ☐ No ☐
Does the tank have a first flush diverter?		Yes ☐ No ☐
Is there overhanging tree branches/vegetation?		Yes ☐ No ☐
Is there evidence of accumulation of debris/leaves?		Yes ☐ No ☐
Are there any visible mosquito larvae in the water?		Yes ☐ No ☐
Is the tank material light proof?		Yes ☐ No ☐
Condition of the tank:		☐ visible leaks ☐ cracks ☐ mouldy ☐ damp ☐ other ____________________

Gutter material:		☐ Galvanised steel ☐ Plastic ☐ Zincalum ☐ Other ________________
Are the gutters painted?		Yes ☐ No ☐
if yes …	Gutter paint intact?	Yes ☐ No ☐
Are the gutters fitted with a fire proof gutter mesh system?		Yes ☐ No ☐
Are there gutter outlets fitted on the underside of roof gutters?		Yes ☐ No ☐
Downpipe material:		☐ Galvanised steel ☐ Plastic ☐ Zincalum ☐ Other ________________
Are the downpipes fitted with rain heads?		Yes ☐ No ☐

Gutters/downpipes:

Are the Gutters/tank inlet/outlet free of debris?	Yes ☐ No ☐
Pipes and fittings material:	☐ Galvanised steel ☐ Copper ☐ PVC
What is the pipe grading?	☐ drinking water quality ☐ storm water grade ☐ unknown
How far are the water outlets from the top of the tank?	______ cm

Water Quality

Is the water treated?		Yes ☐ No ☐
if yes …	How?	☐ chlorine ☐ ozone ☐ other ________________
Is the plumbing material marked with the "Australian Standard Mark" 5 ticks, W (water mark) or T (type tested) - comply *with AS/NZS 3500*?		Yes ☐ No ☐
Are all above ground service pipes clearly marked at intervals not exceeding one meter with the contrasting coloured wording '**RAINWATER**' *or* **"UNTREATED WATER"**?		Yes ☐ No ☐
Are all water outlets labelled '**RAINWATER/UNTREATED WATER'** or taps identified with a green coloured indicator with the letters '**RW'** in accordance with *AS/NZS 1345*?		Yes ☐ No ☐
Is there a Boil Water Alert sign posted?		Yes ☐ No ☐
Does the water look clean/colourless?		Yes ☐ No ☐
Is the water odourless?		Yes ☐ No ☐
Are there any signs related to water quality at the outlet points?		Yes ☐ No ☐
If yes …	Sign posting clearly visible/readable?	Yes ☐ No ☐
When the tank inlet filter was last cleaned?		☐ Date_______________ ☐ unknown
When the tank was last desludged?		☐ Date_______________ ☐ unknown
When the gutters were last cleaned?		☐ Date_______________ ☐ unknown
Is the water regularly tested/monitored		Yes ☐ No ☐ unknown ☐

If yes …	How frequently is water tested?	☐ Bi-weekly ☐ Quarterly ☐ Annually ☐ unknown ☐ other ________________________
	Which parameters are tested for?	☐ Microbiology ☐ Chemicals ☐ visual

Water sampling/testing

Was there any sampling carried out at this site?		Yes ☐ No ☐
if yes …	Where was the water sample taken from?	☐ Tank ☐ Tap ☐ other ________________________
	Water temperature:	°C
	Water pH:	
	Free chlorine	
	Total chlorine	
	Turbidity	
	Alkalinity	
	Lab results	Yes ☐ No ☐ Not applicable ☐
Has there been recent rainfall?		Yes ☐ No ☐
if yes …	When was the last period of rainfall?	

	What was the duration of the rainfall?	
	What was the type of rainfall?	☐ light ☐ moderate ☐ heavy

Management Plan

Is there a Management Plan for this area?	Yes ☐ No ☐
Notes: ____ ____ ____ ____	

Inspection carried out by:

____

Appendix 7: Recreational Parks First and Second Survey Results

Park	Water source	Storage	Type	Boil water alert		Treatment		Quality Assurance Plan		Warning sign	
				Before	**After**	**Before**	**After**	**Before**	**After**	**Before**	**After**
Crowdy Gap	Rain	Tank	P	N	N	N	N	N	Y	Y	Y
Sailing Club	Retic	N/A	N/A	N/A	N/A	Y	Y	N/A	N/A	N/A	N/A
Santa Barbara	Retic	N/A	N/A	N/A	N/A	Y	Y	N/A	N/A	N/A	N/A
Kylies Camp	Bore	Tankx2	G	N	N	Y	Y	N	Y	Y	Y
Diamond Head	Bore	Tank	G	N	N	Y	Y	N	Y	Y	Y
Banksia Green	Rain	Tank	G	N	N	N	N	N	Y	Y	Y
Wallingat Camp	Rain	Tankx2	C/P	N	N	N	N	N	Y	N	Y
Indian Head	Bore	Tank	G	N	N	Y	Y	N	Y	Y	Y
Glenbawn	Dam	Nil	N/A	N	N	N	Y-New	N	Y	N	Y
Liddell	Carted	Tankx2	C	N	N	N	Y-New	N	Y	N	Y
Korsmans Landing	Rain	Tank	P	N/A	N	N/A	N	N/A	Y	N/A	Y
Boomeri Camp	Rain	Tank	G	N	N	N	N	N	Y	Y	Y
Northern Broadwater	Rain	Tank	G	N	N	N	N	N	Y	Y	Y
The Wells	Rain	Tank	G	N	N	N	N	N	Y	Y	Y

Dees Corner	Rain	Tank	G	N	N	N	N	N	Y	Y	Y
Mungo Brush	Rain	Tankx2	G	N	N	N	N	N	Y	Y	Y
Stewart & Lloyds	Rain	Tank	G	N	N	N	N	N	Y	Y	Y
White Tree	Rain	Tank	P	N	N	N	N	N	Y	Y	Y
Blue Gum Hills	Rain	Tankx2	C/G	N	N	N	N	N	Y	Y	N-Rmvd
Casuarina	Rain	Tank	C	N	N	N	N	N	Y	Y	Y
Onley Basin	Rain	Tank	C	N	N	N	N	N	Y	Y	Y
Onley State	Rain	Tank	C	N	N	N	N	N	Y	Y	Y
Onley Headquarters	Rain	Tank	C	N	N	N	N	N	Y	Y	Y
Tapin Tops	Rain	Tank	P	N	N	N	N	N	Y	Y	Y
Glenrock	Retic	N/A	N/A	N/A	N/A	Y	Y	N/A	N/A	N/A	N/A
Thungutti	Rain	Tank	C	Y	N	N	N	N	Y	Y	Y
Wollomombi	Carted	Tankx2	C	N	N	Y	Y	N	Y	Y	Y
Banksia Point	River	Tankx2	P	Y	N	N	N	N	Y	Y	Y
Toms cabins	River	Tank	G	N	N	N	N	N	Y	N	Y
Point Lookout	Rain	Tank	G	Y	N	N	N	N	Y	Y	Y
Long Point	Rain	Tank	C	Y	Dcom	N	Dcom	N	Decom	N	Decom

Dangar Gorge	Carted	Tank	C	N	N	Y	Y	N	Y	Y	Y
Split Rock	Dam	Tank	C	Y	N	N	Y	N	Y	Y	Y
Boonoo Boonoo	Carted	Tank	C	N	Y	N	N	N	Y	Y	Y
Goonooowigal	Rain	Tank	P	Y	Y	N	N	N	Y	N	Y
Berrangutta	Rain	Tank	C	Y	N	N	N	N	Y	N	Y
Mulligans	Rain	Tank	C	Y	Y	N	N	N	Y	N	Y
Mother of Ducks	Retic	N/A	N/A	N/A	N/A	Y	Y	N/A	N/A	N/A	N/A
Bellbird	River	Tank	C	Y	N	N	N	N	Y	Y	Y
Sawn Rocks	Rain	Tankx2	C	Y	Dcom	N	Dcom	N	Decom	Y	Y
Rawson	Spring	Tankx2	C	N	N	Y	Y	N	Y	N	Y
Lake Keepit	Dam	Tank	G	N	N	Y	Y- Ugrade	N	Y	N	Y
Copeton	Dam	Tank	G	N	N	Y	Y- Ugrade	N	Y	N	Y
Aspley Falls	River	Tank	C	N	Y	N	N	N	Y	N	Y
Dangar Falls	Carted	Tank	C	Y	N	Y	Y	N	Y	Y	Y
Copeland Tops	Rain	Tank	P	N	N	N	N	N	Y	N	Y
Polblue Camp	Rain	Tank	P	N	Y	N	N	N	Y	Y	Y
Polblue Creek	Rain	Tank	P	N	N	N	N	N	Y	N	Y

Polblue Community	Rain	Tank	P	N	N	N	N	N	Y	Y	Y
Chaffey Dam	Rain	Tankx2	C	N	N	N	N	N	N	N	Y
Honey Suckle	Rain	Tank	G	Y	N	N	N	N	Y	N	Y
Warrabah	Carted	Tank	C	N	N	N	Y	N	Y	Y	Y
Boundary Falls	River	Tank	P	Y	N	N	N	N	Y	Y	Y
Wash Pool	Rain	Tank	C	Y	N	N	N	N	Y	N	Y
Dandahra	Bore	Tank	G	N	Y	N	N	N	Y	Y	Y
Raspberry	Rain	Tank	G	Y	Y	N	N	N	Y	Y	Y
Gloucester River	River	Tank	G	N	N	N	N	N	Y	N	Y

Legend:
C = Concrete
G = Galvanised
Decom = Decommissioned
N = No
N/A = Not applicable

P = Plastic
Rmvd = Removed
Ugrade = Upgraded
Y = Yes

Appendix 8: Walhallow Drinking Water Project: AH &MRC Ethics Committee Individual Participant Model Consent Form

AH&MRC ETHICS COMMITTEE

MODEL CONSENT FORM

INDIVIDUAL PARTICIPANT

Project: ……………………………………………………………………………………….

……………………………………………………………………………………………….

Principal Researcher: ……………………………………………………………………….

Research Organisation: …………………………………………………………………….

I, ………………………………………………………………………………………………….

have consented to participate in the above research project on the following basis:

1. I have received the Participant Information Statement and have had the opportunity to ask questions. I understand the purpose of the research and my involvement in it.

2. I have the right to withdraw my consent and cease any further involvement in the research project at any time without giving reasons and without any penalty. This will not affect any services that I receive.

3. Any information I provide during the course of this research will remain confidential. Where the results of the research are published, my involvement and my personal results will not be identified

4. I understand that interviews may be audio-taped or videotaped, but the tapes will be secured and then destroyed at the completion of the project.

5. I understand that if I have any complaints or questions concerning this research project, I can contact the principal researcher, the Chairperson or CEO of the local Aboriginal Community Controlled Health Service; or the Chairperson of the AH&MRC Ethics Committee as follows:
   The Chairperson

AH&MRC Ethics Committee

P.O. Box 1565

Strawberry Hills NSW 2012

Telephone: 9212 4777

Name: ……………………………………………………………………………………….

Signature ……………………………………………….…. *Date* …………..……………..

Witnessed by ……………………………..……………… *Date* ………………………....

Researcher's signature: ……………………………………………

Date …..…………………

Appendix 9: Walhallow Drinking Water Project: AH &MRC Ethics Committee Aboriginal Community Organisation Consent Form

AH&MRC ETHICS COMMITTEE

MODEL CONSENT FORM

ABORIGINAL COMMUNITY ORGANISATION

Name of Aboriginal Community Organisation:

(This must be an Aboriginal Community Controlled Health Service (ACCHS) unless otherwise approved by the Ethics Committee):

…………………………………………………………………………………………………….

Project: ………………………………………………………………………………………….

…………………………………………………………………………………………………….

Principal Researcher: ………………………………………………………………………

Research Organisation: ……………………………………………………………………

This must be completed by the Chairperson or CEO of the Aboriginal community organisation.

I, ……..………………………………………………………………….…………can confirm that the (_____insert name of Aboriginal organisation) gives its consent to the above research project, subject to the following conditions:

1. We have the right to withdraw our consent and cease any further involvement in the research project at any time without any penalty and without giving any reasons.

2. The purpose of the research, as outlined in the attached brief, has been explained we have had the opportunity to ask questions about the project. We have received satisfactory answers to our questions and have been given adequate time to consider the appropriateness of the project.

3. We have been provided with the following information in writing:
   - The names of all people and organisations that are responsible for the security of data and who will have access to the data.
   - Details of the proposed storage and destruction of data.

4. The researcher will need to obtain additional consent from us if there are any changes to the project from the information provided under paragraphs [2] [and [3] above.

5. Any information that any member of our staff provides or any personal details of our clients obtained in the course of this research, are confidential and any information that could identify individual participants will neither be used nor published.

6. Unless otherwise explicitly agreed, any information provided in the course of this research that identifies our organisation or the Aboriginal community which it serves will not be used nor published without our written permission.

7. The researcher will ensure there is continuing consultation with the community and our organisation during the course of the research. The research will not proceed until all required negotiation has occurred to our satisfaction.

8. The ethical provisions relating to the health of Aboriginal people, as set out in AH&MRC and NHMRC publications, will be complied with and the project will not proceed until the AH&MRC Ethics Committee has endorsed the project.

9. The researchers will obtain the written individual consent of all participants in the research.

10. We understand that if we have any complaints or questions concerning this research project, we can contact the principal researcher mentioned above; the Chairperson or CEO, or the Chairperson of the AH&MRC Ethics Committee as follows:

The Chairperson

AH&MRC Ethics Committee

PO Box 1565

Strawberry Hills NSW 2012

Telephone: 9212 4777

-

Signed on behalf of (<u>insert name of Aboriginal organisation</u>)

Signature …………………………………………………………………………………….

Position in the organisation (Board Chair or CEO) ……………………………………….

Date ………….………………

Witnessed by ……………………………..……………… *Date* ………………………..

-

As the Chief Researcher in the project, I acknowledge the conditions set out above

Name: ……………………………………………………………………………………….

Signature………………………………..……………………… Date ………………………

Witnessed by ……………………………..………………. Date ………………………..

Appendix 10: Walhallow Drinking Water Project: Participant Information Statement

I hope you have heard about the community project on drinking water from the previous consultation meetings or from the Local Aboriginal Land Council.

The Walhallow Aboriginal Land Council, on behalf of the community, and the Hunter New England Population Health Unit are currently working together to improve the health of the Walhallow community through improving the quality of the drinking water. We recognise that the link between health and drinking water is important. Drinking water is used for drinking, cooking, mixing beverages, bathing and making tea or coffee among other things.

Hunter New England Population Health is committed to improving the health outcomes for Aboriginal and Torres Strait Islander communities. Working with the communities like Walhallow and finding out their drinking water needs will help us to suggest ways to improve the water quality. As a member of the Walhallow Community over the age of 18 years and living in the community we would like to know what you think about the quality of drinking water in the community. We want to ask you some questions on the following:

- General family information
- Your drinking water choices
- General water management
- General health related to drinking water
- Aboriginal culture and drinking water

It is up to you whether you talk to us about the local drinking water. You don't have to answer all our questions. We will ask you questions from a printed questionnaire. No names or addresses will be collected. The answers will be recorded in a tape recorder and on the printed questionnaire. You can review your answers by asking us to read them back to you.

All information collected will be owned by the Walhallow Aboriginal Land Council. The results of the survey will not contain any names or addresses. The report will be distributed to Hunter New England Population Health, NSW Ministry of Health and James Cook University.

If you would like more information about this assessment please contact:

Jason Allan

Chief Executive Officer

Walhallow Aboriginal Land Council

Phone 0427520680

E-mail wlalc08@bigpond.com

OR

Fidelis Jaravani

Environmental Health Officer

Hunter New England Population Health

Phone 67648000

E-mail fidelis.jaravani@hnehealth.nsw.gov.au

Complaints

This assessment has been approved by the:

- Hunter New England Human Research Ethics Committee of Hunter New England Local Health District (Reference Number 13/10/16/5.06)
- Aboriginal Health and Medical Research Council (Reference number …) and
- James Cook University Human Research Ethics Council (Reference Number …).

If you are concerned about the way this assessment is being carried out or about your rights as a participant or member of Walhallow community please contact:

DR Nicole Gerrand

Manager

Research Ethics and Governance

Hunter New England Health

Locked Bag 1

New Lambton NSW 2305

Phone 49214950 E-mail: Nicole .Gerrand@hnehealth.nsw.gov.au

OR

Rebecca Hancock

Executive Officer

Aboriginal Health & Medical Research Council Ethics Committee

Aboriginal Health & Medical Research Council

P O Box 1565, Strawberry Hills NSW 2012

Phone 92124777

E-mail rhancock@ahmrc,org.au

OR

Jill Anderson

Walhallow Community Health Centre

Health Street

PO Box 3

Caroona NSW 2343

Phone 0267474853

Email jill.anderson@wallhealth.org.au

Appendix 11: Walhallow Drinking Water Project: Aboriginal Community Water Preference Questionnaire

Draft Questionnaire

My name is …………………. from Hunter New England Population Health. I hope you have heard about the community project on drinking water from the previous consultation meetings or from the Local Aboriginal Land Council.

The Walhallow Aboriginal Land Council, on behalf of the community, and the Hunter New England Population Health Unit are currently working together to conduct an assessment of the community drinking water needs. The results of the assessment will help the community to map the required activities to improve the health of the Walhallow community through drinking water of known quality. The assessment will also provide Hunter New England Population Health with opportunities to learn about what issues about drinking water are most important to Walhallow community and what can be done to address those issues.

As a member of the Walhallow Community over the age of 18 years and living in the community we would like to know what you think about the quality of drinking water in the community. We are therefore inviting you to participate in this assessment.

It is important that you should know that your participation in this assessment is voluntary. Should you agree to participate, you are free to withdraw at any time. Your name or address will not be recorded. The answers will be recorded in a voice recorder and on the printed questionnaire.

All information collected will be owned by the Walhallow Aboriginal Land Council.

Do you agree to participate?

A. Participant information

Participant = any community member over 18 years old)

- Gender- male/ female

Age group

16-18	19-24	25-40	41-50	51-65	65-75	76-85	>85

B. Water Preferences

1. Can you describe what you use rain water for?

____

2. Can you explain what you use town water for?

____

2. How would you describe the rain water quality?

____

3. How would you describe the town water?

____

4. How would you rank the water quality between 1 and 7 with 1 being the best and 7 the worst.

Water source	Water characteristic						
	taste	smell	appearance	pressure	reliability	safety	Hardness
Town							
Rainwater							

5. Which water characteristic do you consider the most important? Rank between 1 and 7 with 1 being the best and 7 the least.

Water source	Water characteristic						
	taste	smell	appearance	pressure	reliability	safety	hardness
Rainwater							
Town							

6. Which water source do you trust most? Town/Rainwater

Why? ____

7. Which supply do you recommend to your children? Town/Rainwater
Why? ____

8. Which supply do you recommend to your visitors? Town/Rainwater
Why? ---

9. If rain water were to run dry, would you drink town water? Yes/No

10. If your answer is 'No', can you explain why?
    ____
11. If town water were to run dry, would you drink rain water? Yes/No

12. If your answer is 'No', can you explain why?
    ____
13. When you visit town do you drink town water? Yes always/Yes sometimes/Never

14. If never, what do you drink if you become thirsty?
    ____
15. Can you explain why you do this?
    ____
16. Can you tell me about a time when you went away from Walhallow and what you did about drinking water?
    ____
17. When your children go to school do they carry drinking water with them? Yes/No
18. If your answer is 'Yes', which water?
    ____
19. Can you explain why the children carry the water to school?
    ____

C. Water management

1. How would you describe drinking water maintenance in Walhallow?

1 = very good; 2 = good; 3 = bad; 4 = very bad

Rain water	
Town water	

2. If any improvements were to be made which issues would you prefer to be addressed first? Rank them 1-8 (1 for the highest; 8 for lowest priority).

Water source	Water character							
	taste	smell	appearance	pressure	reliability	safety	Maintenance program	Hardness
Rainwater								
Town water								

3. If only one water source were to be improved which water would you prefer? Town/ Rainwater (Circle one).

Why? ---

4. Who do you think should best be responsible for the water maintenance?

Why? ____

D. Culture

1. Do you use the water for any cultural purposes? Yes/No
2. If yes, which water supply? Town/Rainwater
3. Can you describe what type of cultural purposes?
   ____
4. Does the source of the water have any influence on your choice of water? Yes/No
5. Can you describe what the influence is?
   ____
6. Does the quality of the water have any influence on the choice of water? Yes/No

7. Can you describe what the influence is?
____
8. Which water quality criteria do you consider most when using the water for cultural purposes?
9. Can you explain why?
____

F. History

In relation to the history of Walhallow, from a long time ago to more recently, what are some of the issues that relate to the safety of drinking water?

____
____
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Do you have any other issues pertaining to drinking water in Walhallow which you would want to be addressed?

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Appendix 12: Walhallow Aboriginal Corporation Letter of Project Support

WALHALLOW
ABORIGINAL CORPORATION
WAC ABN: 16 209 174 798

PO Box 129, CAROONA NSW 2343
Tel: 02 67474854 or 02 67474865
Fax: 02 67474930 ICN No: 69

Att: Fidelis

Re: Walhallow Community Water Project

The Walhallow Aboriginal Corporation fully supports the Walhallow Community Water Project.

We understand that the aim of the project is:

- To gain a shared understanding with the Walhallow Aboriginal community and Hunter New England Population Health about the qualities of the drinking water supplies and, explore community concerns about reticulated water supplies.

The objective of the study we agree to are:

- To understand Walhallow communities concerns about the drinking water supplies
- To build community trust in governmental agencies involved in drinking water safety.
- To inform the next steps in working with the communities to improve drinking water safety

We understand that the project will be conducted through 2014 to 2016 but that it will require ethics approval by the Hunter New England, James Cook University and the Aboriginal Medical Research Council.

The Walhallow Aboriginal Corporation is happy to work with you and the research team and look forward to the outcomes of the project. Safe drinking water is essential for the health of our community.

The continued support for the project is dependent on the research project continuing to be conducted in a respectful way and ensuring that the community is fully informed and engaged in the project.

If further information is required, please do not hesitate to contact.

Regards,

CEO Cheryl Porter
Walhallow Aboriginal Corporation

SEWB Office: 72 George Street, Quirindi NSW 2343 Ph: 02 67462001 Fax: 02 67462008.

Appendix 13.1 Ethics Approval Drinking Water Quality in Hunter New England

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Appendix 13.2 Ethics Approval HNEHREC

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Appendix 13.3 JCU Ethics Approval

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Appendix 13.4 JCU Walhallow Ethics Approval H5531

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Appendix 13.5 AH&MRC Application Ethics Approval - Mtg 01-14 (984-13)

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